NASA Contractor Report 165932

Development of Flying Qualities Criteria for Single-Pilot Instrument Flight Operations: Interim Report

Aharon Bar-Gill, W. Barry Nixon
and George E. Miller

FLIGHT RESEARCH LABORATORY
PRINCETON UNIVERSITY
Princeton, N.J. 08544

CONTRACT NAS1-15764
June 1982

National Aeronautics and
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ABSTRACT

Research is being conducted to develop flying qualities criteria for Single Pilot Instrument Flight Rule (SPIFR) operations. Significant progress has been made with regard to most of the key issues encompassed in the SPIFR research program. The ARA aircraft has been modified and adapted for SPIFR operations. Aircraft configurations to be flight-tested have been chosen and matched on the ARA in-flight simulator, implementing modern control theory algorithms. Mission planning and experimental matrix design have been completed. Microprocessor software for the onboard data acquisition system has been debugged and flight-tested. Flight-path reconstruction procedure and the associated FORTRAN program are at a final stage of development. Work has begun on algorithms associated with the statistical analysis of flight test results and the SPIFR flying qualities criteria deduction.

PREFACE

This investigation is being conducted by the Flight Research Laboratory at Princeton University, Princeton, New Jersey under Contract No. NAS1-15764 for the NASA Langley Research Center. This is the first annual technical report, and it reflects the SPIFR research effort through May 1981.

The principal investigator for the study is Professor Robert F. Stengel. He is assisted by W. Barry Nixon, senior technical staff member, George E. Miller, technical staff member, Aharon Bar-Gill, graduate student, Thomas O. Williams, technical staff member, Barton C. Reavis, technical associate and electronic technicians Louis Pokrocos, Thomas Frobose and Karl Thomas.

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LIST OF SYMBOLS

Variables	Description
$\underline{a}_B$	acceleration vector in body axes, "g"
a_x, a_y, a_z	cartesian components of $\underline{a}_B$, "g"
C	implicit model following gain matrix
F	system dynamics matrix
$\underline{f}$	nonlinear functions for vehicle equations of motion
G	control effects matrix
g	gravitational acceleration, ft/sec^2
H	observation matrix
	transformation matrix
h	altitude, ft
$\underline{h}$	nonlinear measurement functions
I	identity matrix
K	Kalman gain matrix
L	transformation matrix
$M_{( )}$	pitch moment stability-and-control derivative
$n_{( )}$	random noise associated with the ( ) variable
P	state covariance matrix
p	roll rate, deg/sec
Q	process noise covariance matrix
q	pitch rate, deg/sec
R	measurement noise covariance matrix
r	yaw rate, deg/sec
S	intermediate command output matrix
s	Laplace transform variable
T	duration of flight segment to be reconstructed, sec

t	time, sec
u	x-axis velocity, ft/sec
$\underline{u}$	control vector
$\underline{V}_{air}$	airspeed vector, ft/sec
v	y-axis velocity, ft/sec
$\underline{v}$	measurement noise
w	z-axis velocity, ft/sec
$\underline{w}$	process noise vector
$\underline{W}_I$	wind vector in inertial frame, ft/sec
$X_{(\ )}$	(aerodynamic + thrust)-force along the x-axis derivative
x_I	axial position in inertial frame, ft
$\underline{x}$	state vector
y_I	lateral position in inertial frame, ft
$\underline{Y}$	command vector
$Z_{(\ )}$	(aerodynamic + thrust)-force along the z-axis derivative
z_I	vertical position in inertial frame, ft
$\underline{z}$	observation vector

Variables (Greek)

α	angle of attack, deg
β	angle of sideslip, deg
δE	elevator deflection, deg
δF	flap deflection, deg
δT	throttle deflection, percent
θ	pitch attitude angle, deg
Σ	summation
Φ	state transition matrix
ϕ	roll attitude angle, deg
ψ	yaw attitude angle, deg
$\tilde{\omega}$	body angular rate skew matrix
$\underline{\omega}$	angular rate vector

Superscripts

B	transformation to body axes
I	transformation to inertial axes

Subscripts

A	kinematic model A
ARA	Avionics Research Aircraft
B	body-axis frame
	from body axes (with transformation matrix)
	kinematic model B
	feedback
	backward filter
comm	commanded (desired) value
F	feed forward
I	inertial frame
	from inertial axes (with transformation matrix)
i	navigation station sequencing index
k	sampling instant index
M	model
o	nominal value
q	sensitivity to pitch rate
u	sensitivity to x-axis velocity
w	sensitivity to z-axis velocity
δE	sensitivity to elevator deflection
δF	sensitivity to flap deflection
δT	sensitivity to throttle deflection

Punctuation

$\dot{(\ )}$	derivative of quantity with respect to time
$\underline{(\ )}$	vector quantity
$\delta(\ )/\delta(\ )$	partial derivative of one variable with respect to another

$\Delta( )$	perturbation variable
$( )^*$	steady-state variable
$( )^T$	transpose of a vector or matrix
$( )^{-1}$	inverse of a matrix
$(\hat{})$	estimated value of a variable
$( )^\#$	pseudoinverse of a matrix
s( )	sin( )
c( )	cos( )

Acronyms

A/D	analog-to-digital
ADF	automatic direction finder
ARA	Avionics Research Aircraft
CDU	control-display unit
CHR	Cooper-Harper Rating
D/A	digital-to-analog
DME	distance measuring equipment
FBW	fly-by-wire
FRL	Flight Research Laboratory
GA	general aviation
GDOP	geometric dilution of precision
IAS	indicated airspeed
IFR	instrument flight rule
I/O	input/output
POR	pilot opinion rating
PROM	programmable read-only memory
RAM	random access memory
SBC	single-board computer
SPIFR	single-pilot instrument flight rule
TAS	true airspeed
VFR	visual flight rule
VOR	very-high-frequency omni-range

1. INTRODUCTION

1.1 BACKGROUND AND GOALS

This investigation of Single-Pilot Instrument Flight Rule (SPIFR) flying qualities criteria focuses on General Aviation (GA) operations. General Aviation plays an important role in this nation's transportation network (there are about 200,000 active GA aircraft, with the projected number for 1990 being about 300,000), but the difficulty of piloting and the inherent hazards associated with the SPIFR flight regime pose obstacles to continued growth of this mode of transportation (Ref. 1).

An important effect which contributes to an increased hazard for SPIFR operation is the low-frequency dynamic response of a GA aircraft, which does not have to comply with any federal aviation regulation (Ref. 2). As a result, most contemporary GA aircraft have, at best, a marginally stable phugoid mode which may become divergent under wind shear conditions (Ref. 3). This dynamic response problem generally can be coped with under VFR conditions, although it increases pilot's workload significantly. In typical commercial flight, the IFR workload is shared by two pilots; however, GA IFR flight often is controlled by a single pilot. Airframe dynamic deficiencies, finite capabilities of the human operator, and the often limited capabilities of communications and navigation equipment available in typical GA aircraft compound the flight problem under SPIFR conditions.

Prior research has addressed separately various issues, which coupled together, result in this unique flight mission/regime. For example, Ref. 4 and 5 look into the dynamic response

characteristics of GA aircraft, Ref. 6 presents the effect of advanced cockpit controls and displays, and Ref. 7 addresses the pilot workload issue. The SPIFR research initiated by the Flight Research Laboratory (FRL) at Princeton University is an integrated theoretical and flight test program, whose principal objectives are:

- To pursue the trends revealed in previous research,
- To develop new methodologies for analysis of complete SPIFR missions,
- To obtain statistically significant flying qualities criteria for single-pilot instrument flight operations.

1.2 ORGANIZATION OF THE REPORT

Chapter 2 describes the preparation of the ARA for SPIFR mission flights and the onboard experimental setup -- in particular, the hardware and software aspects associated with the data acquisition process. Chapter 3 presents theoretical aspects of the SPIFR research, including modern estimation and control theory algorithms for in-flight simulation and flight path reconstruction. Chapter 4 refers to preliminary flights and to the post-flight data preprocessing procedure verification. Conclusions are contained in Chapter 5. The four appendices contain additional theoretical derivations, program listings for onboard and post-flight processing, description of computer systems employed in this research, and the hardware scheme of the unique DME integration into the SPIFR experimental setup.

2. AIRCRAFT AND DATA ACQUISITION SYSTEM PREPARATION

This chapter describes the preparation of the in-flight simulator and of the onboard digital data acquisition system for SPIFR flight testing. Extensive engineering and technical effort was required for aircraft modifications and rewiring, for new avionics system installation, and for onboard experimental setup integration. The results of this effort are summarized in the following sections.

2.1 AIRCRAFT SYSTEM MODIFICATIONS

The Avionics Research Aircraft (ARA) is a Ryan Navion (N5113K) that has been modified into a fly-by-wire (FBW), variable-stability aircraft (Fig. 2-1). It is capable of simulating a variety of other aircraft using feedback control and command augmentation. The ARA is equipped to measure attitude, angular rates, and linear accelerations in three axes, aerodynamic angles (α, β), airspeed, altitude, and a number of other flight variables. Details of the ARA FBW system can be found in Ref. 8.

The evaluation pilot is to fly a SPIFR mission with the ARA responding as a desired configuration. In an emergency, the safety pilot can override the FBW system and take direct control of the aircraft, (Fig. 2-2).

To be used with the SPIFR program, the ARA had to undergo extensive modifications:

- Design and installation of a modular instrument panel.
- Acquisition and installation of a modern navigation/communication instrument package.
- Addition of secondary workload devices in the cockpit.

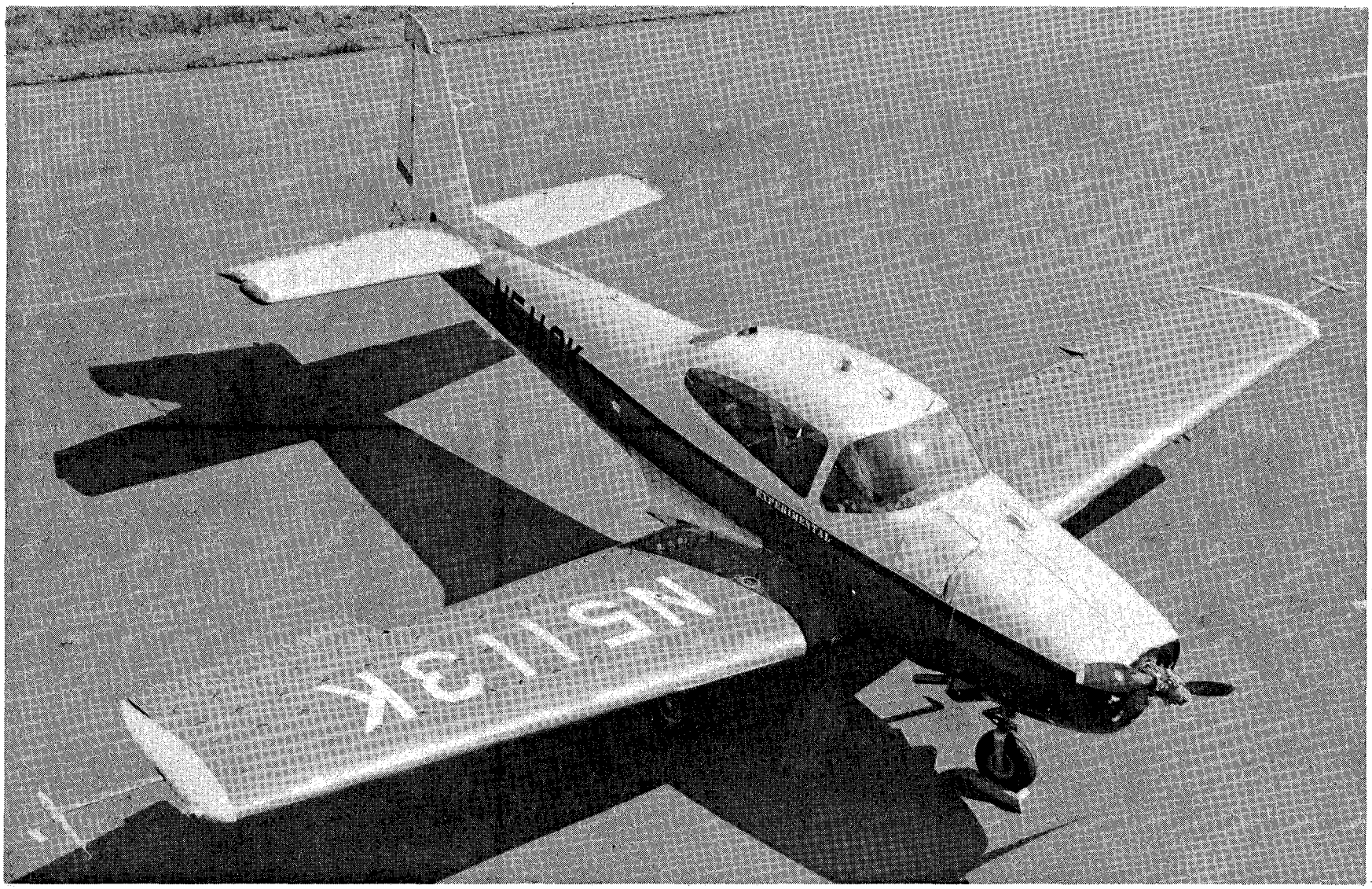


Figure 2-1. Avionics Research Aircraft, Navion N5113K.

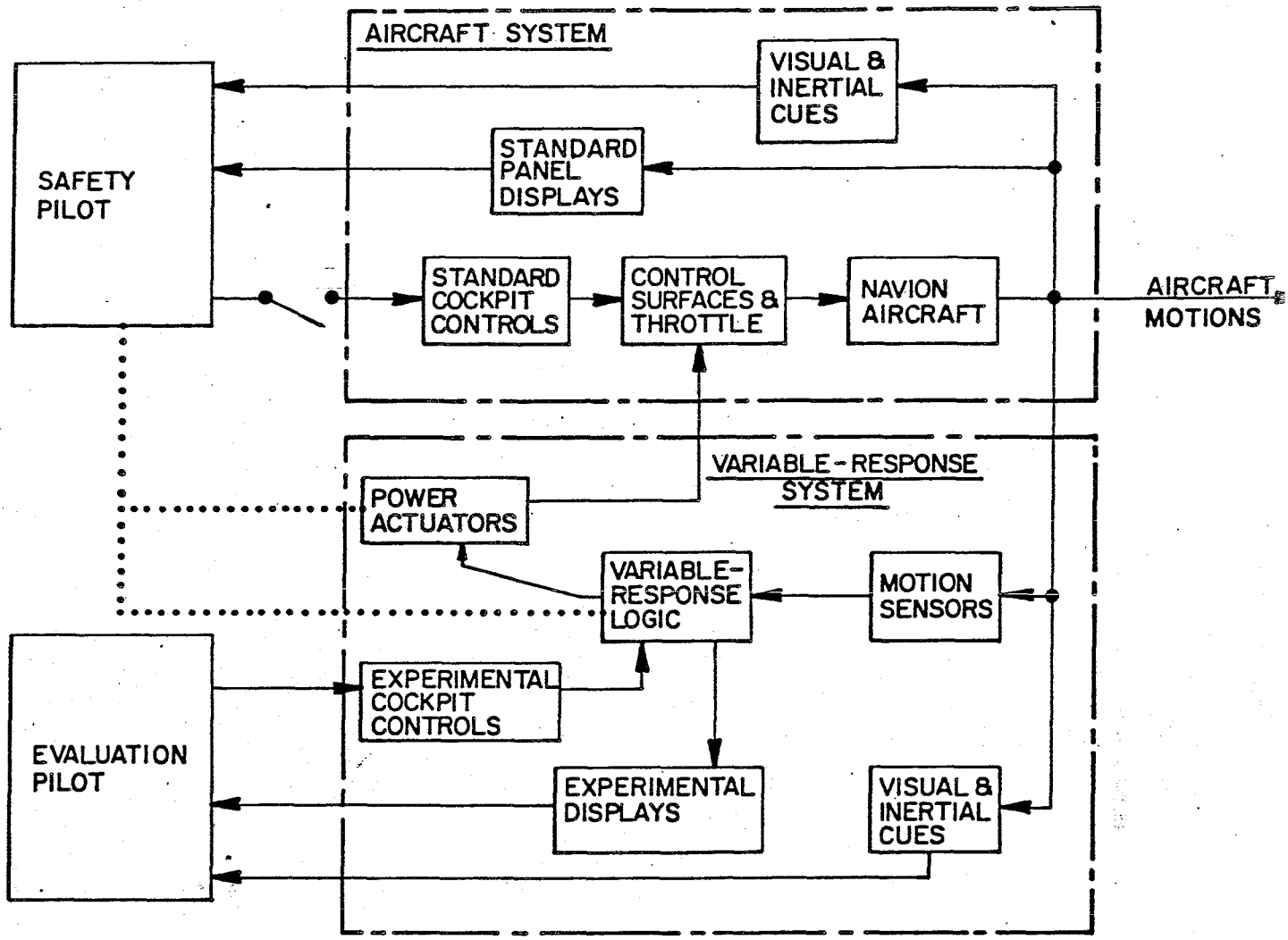


Figure 2-2. Overview of the ARA in-flight Simulator System.

Figure 2-3 illustrates the ARA's modular display panel configuration, with the evaluation pilot's station on the left, the safety pilot's station on the right, and the Bendix BX-2000 navigation/communication stack separating the two. The Distance Measuring Equipment (DME) readout is mounted on a switching panel at the top of the radio stack. The Very-high-frequency Omni-Range (VOR) navigation/communication unit is located under the switching panel. The blank space below this unit is reserved for the Automatic Direction Finder (ADF) and for the transponder.

The DME unit has been integrated into the onboard experimental setup, maintaining the capability to sequence the available navigational stations automatically (through microprocessor control). The importance of this option is discussed in Section 3.5. The technical implementation details are presented in Appendix D.

The safety pilot's panel is a permanent fixture, with conventional instruments and elements for control of the variable-stability system. The latter occupy the right side of the panel and the lower and middle consoles. The evaluation pilot's panel can be removed as a unit to facilitate installation of alternate panels for other investigations. Secondary workload meters, lights, and switches also have been added to the panel.

The secondary workload meters are additional instruments slaved to the onboard microprocessor, which occasionally forces the needles into their "red zones". The evaluation pilot is instructed to keep them "green". Alternately, the pilot can be asked to extinguish lights turned on (pseudorandomly) by the microprocessor program. It is also possible to

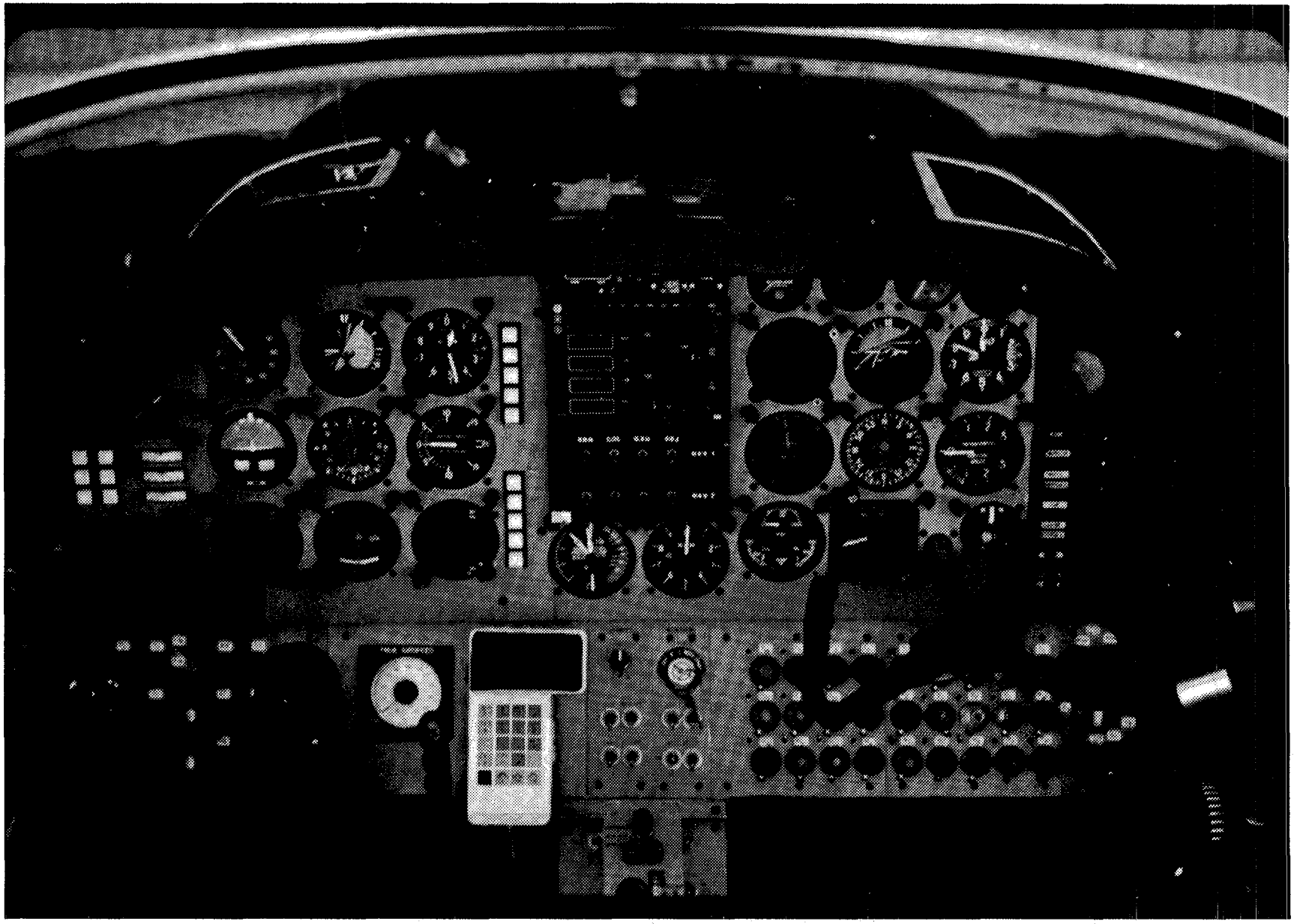


Figure 2-3. Cockpit Displays of the Avionics Research Aircraft. Modular SPIFR Evaluation Pilot Panel at Left.

simulate typical communications workload by blending audio inputs from a pre-recorded tape with specific instructions radioed from the ground on the flight test frequency.

2.2 INSTRUMENTATION AND DATA RECORDING SYSTEM

The SPIFR digital data acquisition system is illustrated in Fig. 2-4. It is built around the SPIFR microcomputer, which uses the Z-80A central processing unit and the Am9511 mathematics processor in a Multibus™ architecture. As currently configured, the SPIFR microcomputer contains 48K bytes of RAM (random access memory) and 16K bytes of PROM (programmable read-only memory). It accepts 32 analog inputs and produces 6 analog outputs.

The ARA's safety pilot communicates with the SPIFR Microcomputer through a hand-held control/display unit (CDU), the Termiflex HT/4. The pilot is able to start and stop processing or recording through the CDU, change stored numerical values, and so on. Conversely, the CDU can display internally triggered error messages to the safety pilot. The evaluation pilot normally is unaware of the SPIFR Microcomputer's operation, other than through secondary workload stimuli and responses.

Analog and digital inputs and outputs shown in Fig. 2-4 are, for the most part, self-explanatory. Tables 2-1 and 2-2 contain lists of inputs and outputs. The SPIFR Microcomputer obtains its analog inputs from the Digital Avionics Research System (DARE) junction box (J-Box) previously installed in the ARA for another Langley Research Center program. Thus, there is a high degree of "plug compatibility" between the SPIFR and DARE programs.

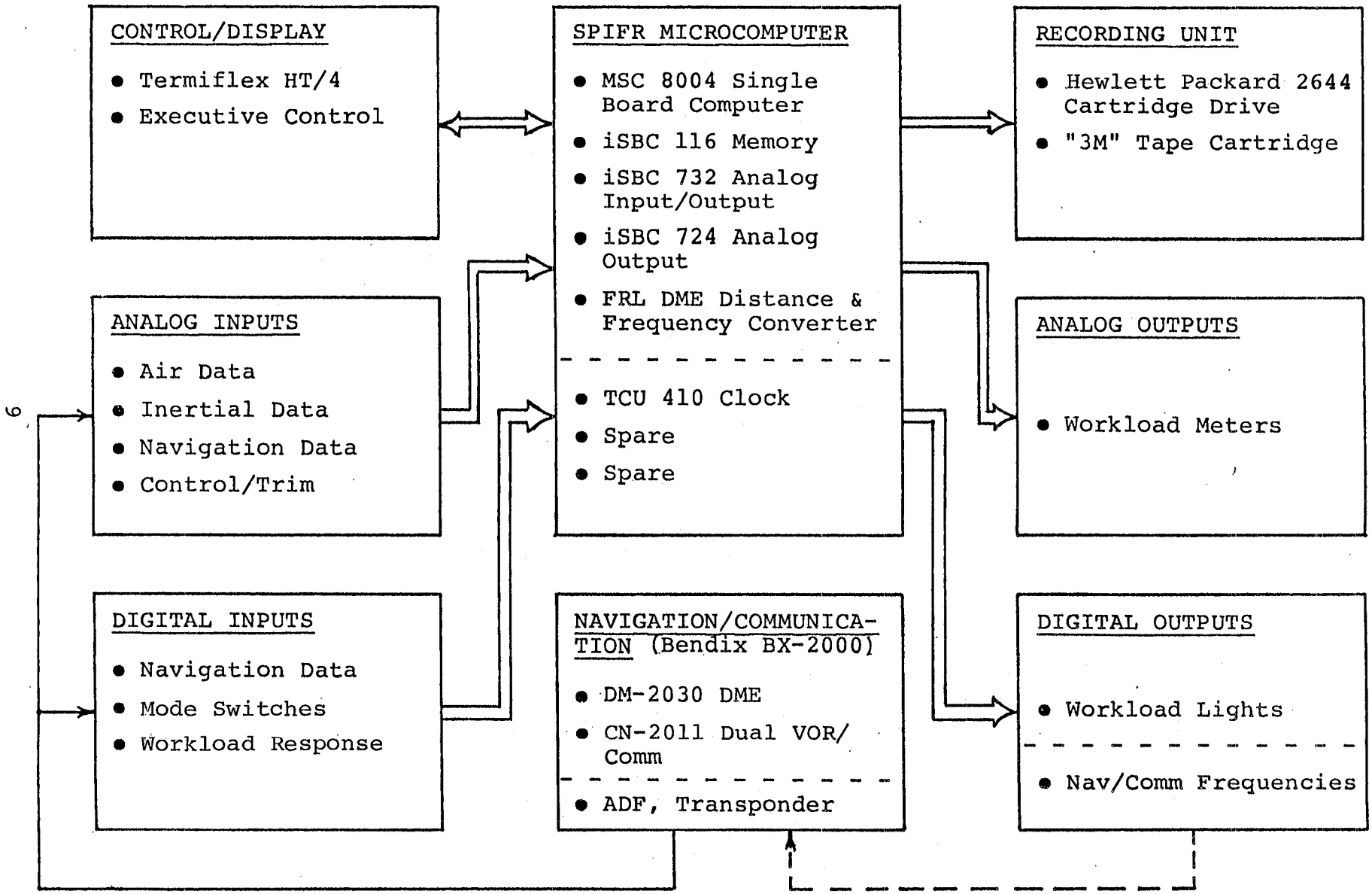


Figure 2-4. SPIFR Digital Data Recording System.

TABLE 2-1

Input Assignments For

SPIFR Digital Data Recording System

Analog Inputs

1. Control Column Angle
2. Throttle Setting
3. Flap Command
4. Angle of Attack
5. Pitch Angle
6. Pitch Rate
7. Airspeed
8. Control Wheel Angle
9. Foot Pedals
10. Sideslip Angle
11. Roll Angle
12. Yaw Angle
13. Roll Rate
14. Yaw Rate
15. Pitch Trim
16. Roll Trim
17. Yaw Trim
18. Normal Acceleration
19. Axial Acceleration
20. Lateral Acceleration
21. VOR#1 Azimuth
22. VOR#2 Azimuth
23. Glide Slope Elevation
24. MLS Azimuth
25. MLS Elevation
26. Radar Altitude
27. Barometric Altitude
28. Stick Force (3rd Year)
29. Simulated Turbulence Level
30. Landing Gear
31. Wind Shear
32. System Engage

Digital Inputs

1. DME Distance
2. VOR#1 Frequency
3. VOR#2 Frequency
4. DME Frequency
5. Time
6. Barometric Altitude
7. ADF Bearing
8. Variable-Stability System Status
9. Pilot Mode Switches (8)
10. Avionics System Status (8)

TABLE 2-2

Output Assignments For

SPIFR Digital Data Recording System

Analog Outputs

1. Secondary workload meter #1
2. Secondary workload meter #2
3. Secondary workload meter #3
4. Spare
5. Spare
6. Spare

Digital Outputs

1. DME tuning
2. DME station indicator
3. Pilot workload lights
4. Avionics System status lights
5. Tape recorder

A presampling filter (16 Hz break-point frequency) has been introduced for each analog channel to filter out the engine-vibration-induced noise.

Figure 2-4 also illustrates the digital radio tuning feature that will be put to use during the second phase of the project. Error budget analyses conducted during the first phase confirmed the superiority of DME over VOR for position fixing, even at the short ranges to be used in our flight tests. Consequently, it is advantageous to substitute multiple DME measurements for VOR measurements in flight data reduction. The BX-2000 DME unit can acquire and lock on a new station in considerably less than one second; this feature will be used in DME-only "round-robin" position fixing for flight path determination.

The digital tape recording unit is the Hewlett Packard (HP) 2644 terminal, which houses two DC100A magnetic tape cartridge drive units. Its built-in memory enables transition from one cartridge to the other without losing any information. Such a pair of cartridges has a storage capability of about 220K bytes, which is more than enough for a complete SPIFR mission run.

To accomodate the complete experimental setup, a pallet to fit into the ARA-aircraft behind the pilots' seats has been designed and built by the FRL technical staff. It weighs 215 lb. and uses the same mounting brackets as the DARE pallet.

2.3 SOFTWARE DEVELOPMENT

The SPIFR program focuses on the low-frequency dynamic response of the airframe and on navigation-related information,

whose rate of change is low as well. On the other hand, as discussed in Section 3.5, simulated SPIFR flight duration has to be about 30 min, during which all the data channels have to be recorded at least every second. Thus, the main objectives of the onboard software design are to:

- Sample the analog data at a high enough rate to avoid aliasing.
- Compress the high frequency data so that the most significant flight test information can be recorded efficiently with minimal error.
- Trigger preprogrammed sequences of the secondary workload devices (lights, dummy meters).
- Enable the safety pilot to operate the data acquisition system via the hand-held CDU.

The information recorded in flight can be separated into "slow" and "fast" variables. The "slow" variables are principally the positional measurements, which can be sampled once per second with minimal aliasing effect. The "fast" variables -- for example, angular rates and linear accelerations -- are sampled 10 times per second. For the sake of data compaction, they are averaged and recorded once each second. The simple averaging process is analogous to "low-pass" filtering. Thus, low-frequency information is passed with little modification, while high-frequency signals are attenuated.

The HP 2644's recording format uses 16-bit binary words. The SBC 732 A/D board is designed to fill in the 12 left-most bit positions of a 16-bit field, and an appropriate shift is performed to comply with the standard output format. Appendix B contains additional detail with regard to the software aspects of the SPIFR onboard data acquisition system, plus the complete listing of the microprocessor assembly program.

3. THEORETICAL ASPECTS OF EXPERIMENT DESIGN AND FLIGHT PATH RECONSTRUCTION

This chapter starts with the presentation of the 6-DOF dynamic model of aircraft motion, as it is applied in the subsequent sections. Section 3.2 discusses the output command algorithm and its implementation to set up a priority list of aircraft configurations to be simulated in the first SPIFR flight test series. The experimental matrix design, based on statistical reasoning, follows in Section 3.3; the application of the chosen configurations on the ARA-in-flight simulator, via the implicit model following algorithm appears in Section 3.4. SPIFR mission planning (Section 3.5) is based mainly on mathematical-statistical modeling of the en-route navigational errors. Finally, the algorithm for post-flight optimal smoothing and flight path reconstruction is presented in Section 3.6.

3.1 AIRCRAFT DYNAMIC MODEL

The general formulation of a nonlinear dynamic model of a system is:

$$\dot{\underline{x}} = \underline{f}\ (\underline{x},\underline{u}) \tag{3-1}$$

where $\underline{x}$ is the state vector and $\underline{u}$ is the control vector. The state vector $\underline{x}$ used here contains three components each of translational rate (u,v,w), translational position (x_I, y_I, z_I), angular rate (p, q, r) and angular attitude (ϕ, θ, ψ). Both body and inertial axis frames are taken right-handed and with z pointing downward. The translational rate equation of the aircraft mathematical model is:

$$\dot{\underline{V}}_{air} = \underline{a}_B + \tilde{\omega}\underline{V}_{air} + H_I^B \underline{g}_I \tag{3-2}$$

The airspeed, expressed in body axes, is:

$$\underline{V}_{air} = [u \; v \; w]^T \tag{3-3}$$

Acceleration, expressed in body axes, is:

$$\underline{a}_B = [a_x \; a_y \; a_z]^T \tag{3-4}$$

The angular rate cross-product-equivalent matrix $\tilde{\omega}$ is defined as:

$$\tilde{\omega} \triangleq \begin{bmatrix} 0 & r & -q \\ -r & 0 & p \\ q & -p & 0 \end{bmatrix} \tag{3-5}$$

The gravity vector in an assumed local level/local north inertial axis system is:

$$\underline{g}_I \triangleq [0 \; 0 \; g]^T \tag{3-6}$$

The transformation matrix H_I^B <u>from</u> inertial (I) <u>to</u> body (B) axes, with [ψ θ ϕ] Euler rotations in the specified order, is:

$$H_I^B \triangleq \begin{bmatrix} c\psi c\theta & s\psi c\theta & -s\theta \\ c\psi s\theta s\phi - s\psi c\phi & s\psi s\phi s\theta + c\psi c\phi & c\theta s\phi \\ c\psi s\theta c\phi + s\psi s\phi & s\psi s\theta c\phi - c\psi s\phi & c\theta c\phi \end{bmatrix} \tag{3-7}$$

where

$$s(\ ) \triangleq \sin(\ )$$
$$c(\ ) \triangleq \cos(\ ) \tag{3-8}$$

The second equation of the aircraft motion 6-DOF mathematical model describes the transformation of body-axis rates to Euler angle rates, and it is

$$\begin{bmatrix} \dot{\phi} \\ \dot{\theta} \\ \dot{\psi} \end{bmatrix} = L_B^I \begin{bmatrix} p \\ q \\ r \end{bmatrix} \tag{3-9}$$

where

$$L_B^I \triangleq \frac{1}{c\theta} \begin{bmatrix} c\theta & s\theta s\phi & s\theta c\phi \\ 0 & c\theta c\phi & -c\theta s\phi \\ 0 & s\phi & c\phi \end{bmatrix} \tag{3-10}$$

The third aircraft equation combines the effects of airspeed $\underline{V}_{air}$ and of the wind vector $\underline{W}_I$ (expressed in inertial axes) to compute translational rate:

$$\dot{\underline{x}}_I = H_B^I \underline{V}_{air} + \underline{W}_I \tag{3-11}$$

where $\underline{x}_I$ is the position vector expressed in inertial axes:

$$\underline{x}_I \triangleq [x_I \ y_I \ z_I]^T \tag{3-12}$$

Based on the orthonormality of H_I^B in eq. (3-7):

$$H_B^I = (H_I^B)^{-1} = (H_I^B)^T \tag{3-13}$$

The following relationships constitute the algebraic part of the model, yielding the output or the measurement models. The airspeed absolute value is:

$$|\underline{V}_{air}| = (u^2 + v^2 + w^2)^{1/2} \tag{3-14}$$

The angle of attack is given by:

$$\alpha = \tan^{-1}(\frac{w}{u}) \tag{3-15}$$

The sideslip angle is:

$$\beta = \tan^{-1}(\frac{v}{u}) \tag{3-16}$$

The definition of the aerodynamic angles with respect to body axes is compatible with the actual measurement mechanization in the ARA.* Assuming that the origin of the inertial frame is at sea level, the altitude h is:

$$h = -z_I \tag{3-17}$$

The acceleration vector $\underline{a}_B$ of eq. (3-2) and (3-4) reflects the effect of aerodynamic and thrust forces, which act on the airframe. For example, the linearized version of eq. (3-1) for the longitudinal case is:

$$\begin{bmatrix} \Delta\dot{u} \\ \Delta\dot{w} \end{bmatrix}_{\underline{a}_B} = \begin{bmatrix} X_u & X_w & X_q \\ Z_u & Z_w & Z_w \end{bmatrix} \begin{bmatrix} \Delta u \\ \Delta w \\ \Delta q \end{bmatrix} + \begin{bmatrix} X_{\delta E} & X_{\delta T} & X_{\delta F} \\ Z_{\delta E} & Z_{\delta T} & Z_{\delta F} \end{bmatrix} \begin{bmatrix} \Delta\delta E \\ \Delta\delta T \\ \Delta\delta F \end{bmatrix} \tag{3-18}$$

The control vector here is:

---

* The sideslip angle definition differs from the conventional definition, which is:

$$\beta = \sin^{-1}\left(\frac{v}{|\underline{V}_{air}|}\right)$$

$$\underline{u} = [\Delta\delta E \ \Delta\delta T \ \Delta\delta F]^T \qquad (3\text{-}19)$$

where δE is the elevator deflection, δT is the throttle travel and δF is the flap deflection.

To complete this illustration of aerodynamic and thrust effects within the context of longitudinal dynamics, the pitch moment (about the center of gravity of the airplane) equation must be introduced:

$$\Delta\dot{q} = M_u\Delta u + M_w\Delta w + M_q\Delta q + M_{\delta E}\Delta\delta E + M_{\delta T}\Delta\delta T + M_{\delta F}\Delta\delta F \qquad (3\text{-}20)$$

Combining eq. (3-18) with eq. (3-20) and fully accounting for the physical effects reflected in eq. (3-2) to (3-10), we obtain:

$$\begin{bmatrix} \Delta\dot{u} \\ \Delta\dot{w} \\ \Delta\dot{q} \\ \Delta\dot{\theta} \end{bmatrix} = \begin{bmatrix} X_u & X_w & -w+X_q & -gc\theta \\ Z_u & Z_w & u+Z_q & -gs\theta \\ M_u & M_w & M_q & 0 \\ 0 & 0 & 1 & 0 \end{bmatrix} \begin{bmatrix} \Delta u \\ \Delta w \\ \Delta q \\ \Delta\theta \end{bmatrix} + \begin{bmatrix} X_{\delta E} & X_{\delta T} & X_{\delta F} \\ Z_{\delta E} & Z_{\delta T} & Z_{\delta F} \\ M_{\delta E} & M_{\delta T} & M_{\delta F} \\ 0 & 0 & 0 \end{bmatrix} \begin{bmatrix} \Delta\delta E \\ \Delta\delta T \\ \Delta\delta F \end{bmatrix} \qquad (3\text{-}21)$$

Equation (3-21) is of the form of a state equation:

$$\underline{\Delta\dot{x}} = F\ \underline{\Delta x} + G\ \underline{\Delta u} \qquad (3\text{-}22)$$

where F is the state matrix and G - the control matrix.

3.2 CANDIDATE SPIFR CONFIGURATIONS VIA THE OUTPUT COMMAND ALGORITHM

The basic assumption underlying the following derivation

is that if a configuration requires large state and control variations to retrim from one nominal SPIFR flight equilibrium to another, it may also be problematic for the pilot.* Thus, to pick the candidate configurations for SPIFR in-flight simulation, we first choose initial configuration parameters and flight equilibrium. Then we examine the required variations in state and control variables, which correspond to various retrimming requirements. The retrimming requirement may be formulated in terms of flight path variables, e.g., variation in airspeed ΔV^* or in flight path angle $\Delta\gamma^*$.

The mathematical formulation uses the output command algorithm (Ref. 9). The following output equation is added to the state equation eq. (3-22):

$$\underline{\Delta y} = H_x \underline{\Delta x} + H_u \underline{\Delta u} \tag{3-23}$$

where $\underline{\Delta y}$ represents the required retrimming flight-path variations. An ideal transition to the new flight equilibrium is assumed:

$$\left.\begin{aligned} 0 &= F\underline{\Delta x}^* + G\underline{\Delta u}^* \\ \underline{\Delta y}_{comm} &= H_x \underline{\Delta x}^* + H_u \underline{\Delta u}^* \end{aligned}\right\} \tag{3-24}$$

where $()^*$ symbolizes the steady-state variations in state and control that correspond to $\underline{\Delta y}$ comm.

As shown in Ref. 9, the solution to eq. (3-24) is:

---

* As used here, a configuration is a set of aerodynamic coefficients which characterizes the dynamic response of the aircraft.

$$\underline{\Delta x}^* = - F^{-1} G S \, \underline{\Delta y}_{comm} \qquad (3\text{-}25)$$

$$\underline{\Delta u}^* = S \, \underline{\Delta y}_{comm} \qquad (3\text{-}26)$$

where:

$$S \triangleq (-H_x F^{-1} G + H_u)^{-1} \qquad (3\text{-}27)$$

As a result of application of the output command algorithm, variations in the following aerodynamic parameters have received priority in the context of SPIFR flight testing:

a) X_u , Z_u , Z_α , M_u

b) $Z_{\delta E}$, $Z_{\delta T}$, $M_{\delta T}$

Stability and control derivatives to be varied in the flight tests fall into two categories: those that affect only trim and those that affect both trim and stability. Control derivatives (list in (b) above) fall into the first category because, as demonstrated by eq. (3-21), they appear in the control matrix G, thus affecting $\underline{\Delta x}^*$ and $\underline{\Delta u}^*$. Stability derivatives (list in (a) above) fall into the second category because they appear in the F matrix, thus affecting both trim and stability.

The ranges of variation of the aerodynamic parameters must reflect the trends in GA aircraft design. These are discussed in the context of the experimental matrix design in the next section.

3.3 EXPERIMENTAL MATRIX DESIGN

The high-priority list of configurations of the previous section has been limited to seven configurations,as we must tradeoff between:

- Number of configurations to be flight-tested.
- Number of replications of SPIFR mission with a given configuration (important for statistical soundness).
- Number of evaluation pilots.

All of this must be done under the constraint of about 25 flight hours.

These tradeoff considerations resulted in the following:

- 15 configurations (nominal ARA and plus/minus variations of each of the 7 coefficients).
- Two test pilots plus one GA pilot.
- Numbers of replications are shown, along with all the other information relevant to the experimental matrix, in Table 3.1. The pluses and the minuses to the right of the numbers of replications describe how many positive and how many negative parameter variations (with respect to nominal) are simulated for each of these numbers.

Parameter to be varied	Test pilot 1	Test pilot 2	GA pilot	Number of mission runs
Nominal	2	2	2	6
X_u	$2\pm$	$2\pm$	$3\pm+$	7
Z_u	$2\pm$	$2\pm$	$3\pm+$	7
M_u	$2\pm$	$2\pm$	$3\pm+$	7
Z_α	$2\pm$	$2\pm$	$3\pm+$	7
$M_{\delta T}$	$2\pm$	$2\pm$	$3\pm+$	7
$Z_{\delta E}$	$2\pm$	$2\pm$	$2\pm$	6
$Z_{\delta T}$	$2\pm$	$2\pm$	$2\pm$	6
			Sum =	53

Table 3.1: Experimental Matrix for the First SPIFR Flight Series.

The ranges of the variations in the aerodynamic parameters are intended to reflect possible trends in GA aircraft design. For example, if the design goal is a configuration with a shorter body, an increase in elevator area may be required in order to preserve its moment effectiveness $M_{\delta E}$. Such an area change may affect the vertical force sensitivity of the elevator $\Delta Z_{\delta E}<0$. On the other hand, introduction of a canard control surface may result in $Z_{\delta E}>0$. Another example may be of a configuration design that features a high wing for improved cabin visibility and wing-mounted shrouded propellers for increased thrust. As a result M_u and $M_{\delta T}$ may be affected by the variations in the aerodynamic forces and the moment arms.

3.4 IMPLEMENTATION OF SPIFR CONFIGURATIONS VIA IMPLICIT-MODEL-FOLLOWING ALGORITHM

The chosen SPIFR configurations are implemented on the in-flight simulator via the implicit-model-following algorithm (Ref. 10). State equations of the type of eq. (3-21) may be written for the nominal ARA configuration (subscript ARA) and for the configurations to be simulated (subscript M),

$$\dot{\underline{\Delta x}}_{ARA} = F_{ARA}\underline{\Delta x}_{ARA}+G_{ARA}\underline{\Delta u}_{ARA} \tag{3-28}$$

$$\dot{\underline{\Delta x}}_{M} = F_{M}\underline{\Delta x}_{M} + G_{M}\,\underline{\Delta u}_{M} \tag{3-29}$$

Our objective is to obtain the control vector $\underline{\Delta u}_{ARA}$, which will make the ARA respond as the required configuration. The perfect model following condition is:

$$\underline{\Delta\dot{x}}_{ARA} = \underline{\Delta\dot{x}}_{M} \tag{3-30}$$

Substituting eq. (3-28) and (3-29) into eq. (3-30) and rearranging:

$$\underline{\Delta u}_{ARA} = G^{\#}_{ARA}[(F_M - F_{ARA})\underline{\Delta x}_{ARA} + G_M \underline{\Delta u}_M] \triangleq$$

$$= C_B \underline{\Delta x}_{ARA} + C_F \underline{\Delta u}_M \tag{3-31}$$

where:

$$G^{\#}_{ARA} \triangleq [G^T_{ARA} G_{ARA}]^{-1} G^T_{ARA} \tag{3-32}$$

Eq. (3-30) renders:

$$\underline{\Delta x}_{ARA} = \underline{\Delta x}_{M} \tag{3-33}$$

Thus, $\underline{\Delta x}_{ARA}$ is the solution of eq. (3-29). A block diagram of the derived algorithm is presented in Figure 3.1.

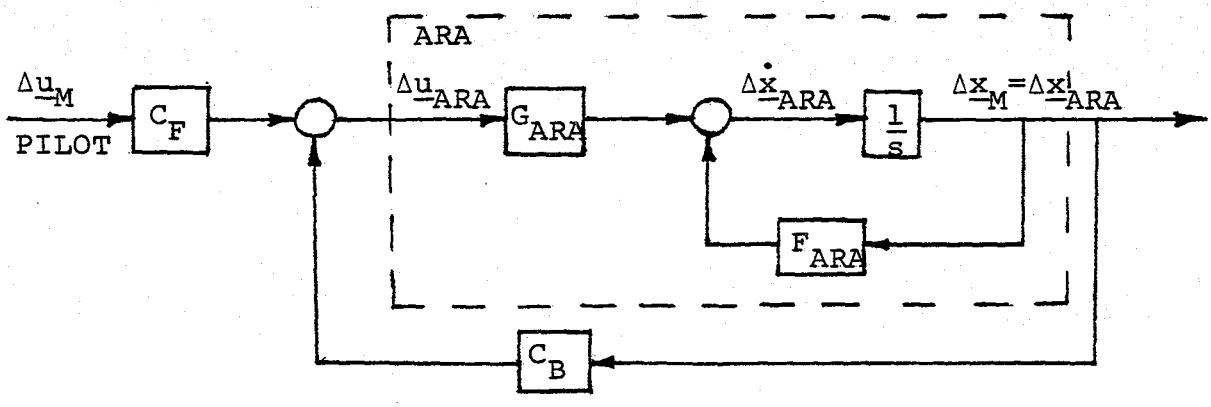


Figure 3.1. Block Diagram for Implementation of a SPIFR Configuration on the ARA In-Flight Simulator.

3.5 EFFECTS OF NAVIGATIONAL ACCURACY AND THE "LEARNING CURVE" EFFECT ON MISSION PLANNING

To simulate realistic SPIFR conditions, the mission has to contain several typical flight-path segments, including

- Climb, acceleration and cruise with airspeed retrimming.
- Holding pattern.
- Deceleration and descent.
- Localizer and glide slope interception.
- Approach and missed-approach go-around.

Also, a realistic VOR-radial navigation should consist of at least once switching navigational stations in the "TO"-mode and of a leg in the "FROM"-mode. The above considerations roughly size the SPIFR mission simulation to a minimum flight duration of about 30 minutes and the geometry shown in Fig. 3-2.

One problem associated with deciding the flight path geometry is the "learning curve" effect. The "learning curve" is the ability of a human being to improve his performance by taking advantage of past experience. Flying all missions along the same trajectory invokes memorization by the pilot, reducing the navigation workload to a level unrealistic for a SPIFR-type mission. To cope with this issue, additional flight path variants have been devised (Fig. 3-3, 3-4, 3-5). All variants are of comparable structure and flight duration.

The other problem associated with the decision of flight path geometry is navigational accuracy. Conclusions of the following discussion with regard to this issue have been implemented with the SPIFR missions of figures 3-2 to 3-5 and, as will be shown, they also contribute to post-flight flight-path reconstruction accuracy improvement.

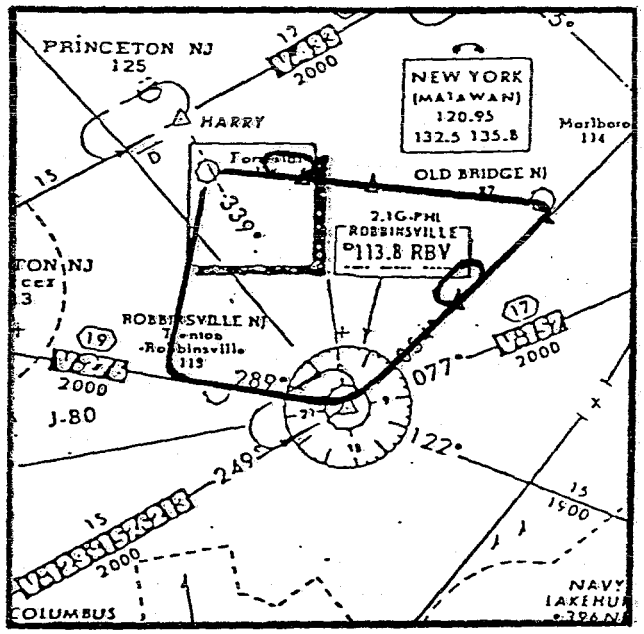


Figure 3-2. Variant I.

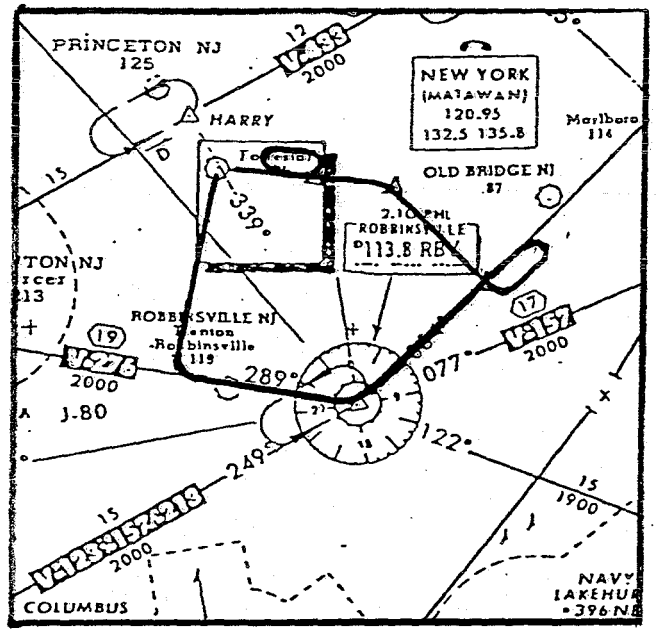


Figure 3-3. Variant II.

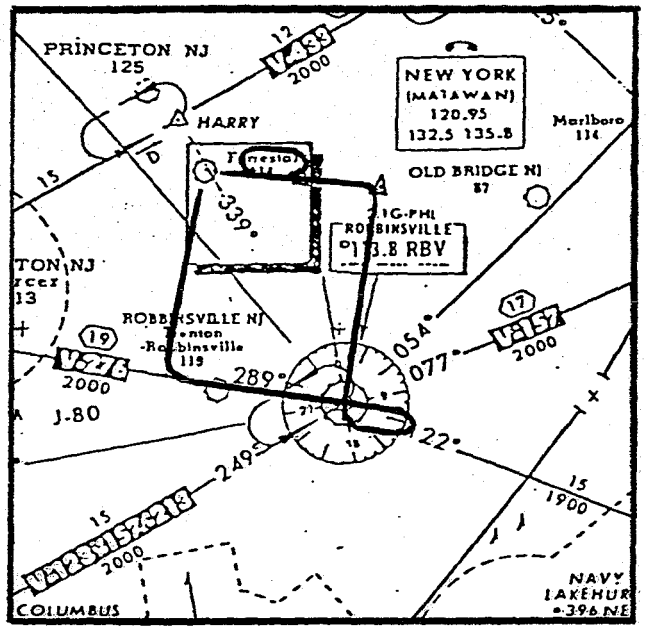


Figure 3-4. Variant III.

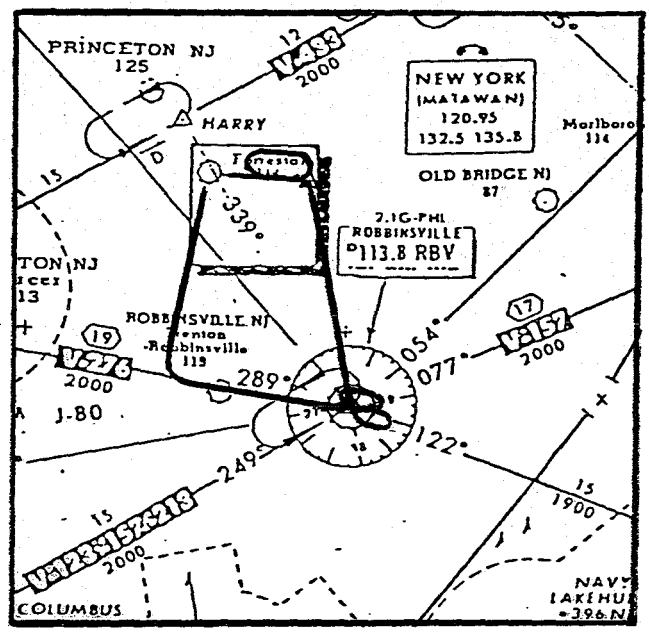


Figure 3-5. Variant IV.

Figures 3-2 to 3-5. SPIFR Flight Path Variants.

The standard navigational modes for GA are VOR/VOR, VOR/DME and DME/DME. At least two navigation stations are required to achieve a horizontal "fix" of the aircraft's position. With proper geometry any of these combinations can provide a fix; however the accuracy of the fix is subject to several factors. The accuracy requirements have been imposed by the Federal Aviation Administration (FAA), and their numerical values appear in Ref. 11.

$$\left.\begin{aligned} \sigma_\psi &\equiv \sigma_{VOR} = 1.9° \\ \sigma_R &= \sigma_{DME} = .15\% \text{ range or } .1 \text{ mile: whichever is larger} \end{aligned}\right\} \qquad (3\text{-}34)$$

These navigational errors are with respect to a single ground station. The position errors associated with a navigational mode have to be computed accounting for the Geometric Dilution of Precision (GDOP) effect. GDOP is an inaccuracy due to the nonperpendicularity of the lines connecting the aircraft with the engaged stations.

Applying analytical geometry to the typical situation depicted in Fig. 3-6 and assuming that the two navigational-

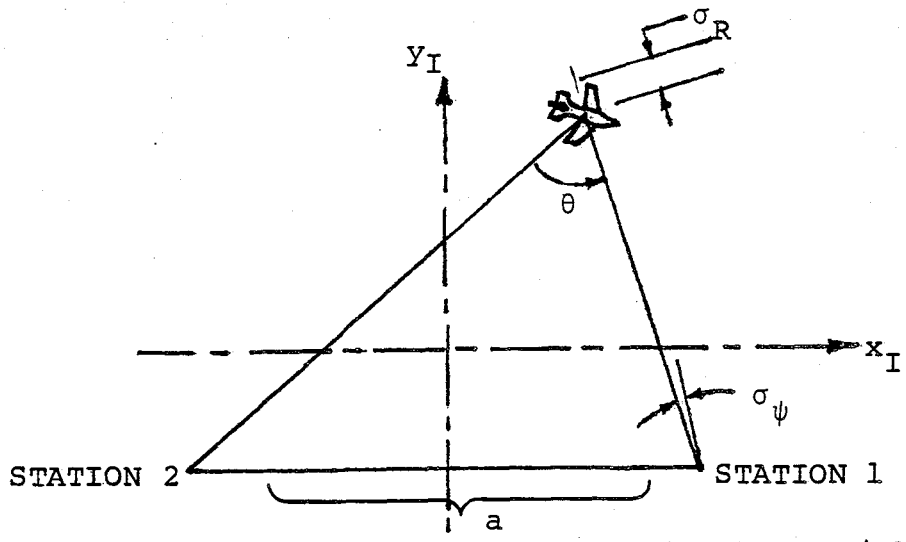


Figure 3-6. Ground Stations Engagement in the VOR/VOR or the DME/DME Modes.

stations' errors are statistically uncorrelated, we obtain:

$$\sigma = (1/s\theta)[\sigma_1^2 + \sigma_2^2]^{1/2} \qquad (3\text{-}35)$$

The $1/s\theta$ term reflects the GDOP effect. For angles between radials in the vicinity of $\theta = 0°$ or $\theta = 180°$, the position error becomes very large, becoming infinite in the limit. To improve position accuracy using two similar ground stations while flying a given leg, it is desirable that the stations be as nearly perpendicular as possible. For VOR/VOR, eq. (3-35) can be rewritten as,

$$\sigma = \frac{a\sigma_\psi}{\sqrt{2}\ s^2\theta}\ (1+s^2\theta)^{1/2} \qquad (3\text{-}36)$$

For DME/DME, eq. (3-35) becomes

$$\sigma = \sqrt{2}\ \sigma_R/s\theta \qquad (3\text{-}37)$$

Numerical values of eq. (3-34) and dependence of $\sigma_{VOR/VOR}$ on the $\sin^2\theta$ suggest that this navigational mode is much less accurate than the DME/DME mode. For example, at a range of 50 miles from both stations and for $\theta = 30°$ the VOR/VOR error is 2.71 miles, while the DME/DME error is 0.28 miles and the results favour the DME/DME pairing at greater ranges. Based on this observation and on the feasibility of microprocessor-controlled sequential engagements of several DME stations, this technique will be employed to improve the flight path reconstruction accuracy. In particular, this accuracy improvement may be achieved by making use of redundant measurements, while applying the optimal Kalman filtering/ smoothing algorithm.

3.6 OPTIMAL SMOOTHING OF FLIGHT-TEST RECORDS AND FLIGHT-PATH RECONSTRUCTION

One way to smooth flight test records is to pass the data through a filter, which chops off the high frequency content of the recorded information. A better way is to account for the particular system's dynamic characteristics. This can be done applying the extended Kalman filter algorithm.

For post-flight analysis, even higher accuracy may be achieved by accounting for the "future" information. This improvement is obtained by using an optimal smoothing algorithm. An additional advantage of this algorithm is that it estimates flight path variables that have not been measured directly. Thus, smoothing and flight path reconstruction are obtained via a single algorithm implementation (as in Ref. 12, 13). For this application we need the system state eq. (3-1), which constitutes a concise representation of eq. (3-2) to (3-13),

$$\dot{\underline{x}} = \underline{f}\ (\underline{x},\underline{u}) + \underline{w} \tag{3-38}$$

and the measurement equation,

$$\underline{z} = \underline{h}\ (\underline{x},\underline{u}) + \underline{v} \tag{3-39}$$

which stands for relationships of the type of eq. (3-14) to (3-17). Equation (3-38) differs from eq. (3-1) by the additional term $\underline{w}$, which is referred to in the literature as "process noise". The vector $\underline{v}$ in eq. (3-39) is the "measurement noise".

Equations (3-18) to (3-31) need not be used in the post-flight optimal smoothing and flight-path reconstruction because the accelerations $\underline{a}_B$ are measured directly. Equations (3-2) to (3-17) constitute a kinematic model, as they do not reflect the dynamic mechanism by which $\underline{a}_B$ is actually produced.

The differential equations of the kinematic model (3-2), (3-9) and (3-11) constitute the "state model" and the algebraic relationships (3-14) to (3-17) the "measurement model". Even without accounting for the $\underline{a}_B$ -producing-mechanism, the kinematic model is nonlinear and high-dimensional. Thus, it is more efficient to tackle it in two steps. This is made possible by the fact that the SPIFR experimental setup records both $[p\ q\ r]^T$ and $[\phi\ \theta\ \psi]^T$. The first step is to smooth these six measurements. Treating all six as state variables and using eq. (3-9) we may write:

$$\text{STATE MODEL A} \begin{cases} \dot{p} = n_p^{\bullet} \\ \dot{q} = n_q^{\bullet} \\ \dot{r} = n_r^{\bullet} \\ \dot{\phi} = p + \tan\theta\,(s\phi * q + c\phi * r) \\ \dot{\theta} = c\phi * q - s\phi * r \\ \dot{\psi} = \frac{1}{c\theta}(s\phi * q + c\phi * r) \end{cases} \tag{3-40}$$

$$\text{MEASUREMENT MODEL A} \begin{cases} \underline{z}_A = H_A \underline{x}_A + \underline{v}_A \end{cases} \tag{3-41}$$

The state vector for model A is:

$$\underline{x}_A = [p\ q\ r\ \phi\ \theta\ \psi]^T \tag{3-42}$$

The process noise vector (with $n_p^{\bullet}$, $n_q^{\bullet}$ and $n_r^{\bullet}$ random and unknown angular acceleration inputs) is:

$$\underline{w}_A = [n_p^{\bullet}\ n_q^{\bullet}\ n_r^{\bullet}\ 0\ 0\ 0]^T \tag{3-43}$$

The measurement noise vector for model A is:

$$\underline{v}_A = [n_p \; n_q \; n_r \; n_\phi \; n_\theta \; n_\psi]^T \tag{3-44}$$

The measurement vector $\underline{z}_A$ in (3-41) contains the measured values of $\underline{x}_A$. Thus, the observation matrix H_A is an identity matrix.

Before elaborating on the optimal smoother algorithm implementation based on eq. (3-40) and (3-41), the kinematic model for the second step is now derived. We assume that the time histories,

$$\hat{p}(t), \; \hat{q}(t), \; \hat{r}(t); \; \hat{\phi}(t), \; \hat{\theta}(t), \; \hat{\psi}(t) \tag{3-45}$$

and the associated matrices,

$$\hat{H}^I_B(t) \quad , \quad \hat{H}^B_I(t) \quad , \quad \hat{\tilde{\omega}}(t) \tag{3-46}$$

are given, having completed the first step. The 6-component state vector for the next step is,

$$\underline{x}_B = [x_I y_I z_I \; u \; v \; w]^T \tag{3-47}$$

and the 6-component input vector is,

$$\underline{u}_B = [w_{x_I} w_{y_I} w_{z_I} \; (a_x - s\hat{\theta}g) \; (a_y + c\hat{\theta}s\hat{\phi}g) \; (a_x + c\hat{\theta}c\hat{\phi}g)]^T \tag{3-48}$$

The input vector contains components of the <u>true</u> wind and accelerations, $\underline{w}_I$ and $\underline{a}_B$. In this context, the actual values of these measured variables are interpreted as inputs and their measurement inaccuracies as process noise*:

---

* Appendix A presents an improved wind model.

$$\underline{w}_B = [0\ 0\ 0\ n_{a_x}\ n_{a_y}\ n_{a_z}]^T \tag{3-49}$$

Unlike the first step, in which the $\underline{x}_A$ components have been smoothed optimally, this step reconstructs the $\underline{x}_B$ components with eq. (3-2) and (3-11) constituting the state model B:

$$\text{STATE MODEL B} \begin{cases} \begin{bmatrix} \dot{x}_I \\ \dot{y}_I \\ \dot{z}_I \end{bmatrix} = \hat{H}_B^I(t) \begin{bmatrix} u \\ v \\ w \end{bmatrix} + \begin{bmatrix} w_{x_I} \\ w_{y_I} \\ w_{z_I} \end{bmatrix} \\ \begin{bmatrix} \dot{u} \\ \dot{v} \\ \dot{w} \end{bmatrix} = \hat{\tilde{\omega}}(t) \begin{bmatrix} u \\ v \\ w \end{bmatrix} + \begin{bmatrix} a_x - s\hat{\theta}g \\ a_y + c\hat{\theta}s\hat{\phi}g \\ a_z + c\hat{\theta}c\hat{\phi}g \end{bmatrix} + \begin{bmatrix} n_{a_x} \\ n_{a_y} \\ n_{a_z} \end{bmatrix} \end{cases} \tag{3-50}$$

Equations (3-14) to (3-17) plus VOR and DME measurement equations constitute the measurement model B:

$$\text{MEASUREMENT MODEL B} \begin{cases} |\underline{V}_{air}| = (u^2+v^2+w^2)^{1/2} + n_v \\ \alpha = \tan^{-1}(\frac{w}{u}) + n_\alpha \\ \beta = \tan^{-1}(\frac{v}{u}) + n_\beta \\ h = -z_I + n_h \\ r_{DME_{si}} = [(x_I-x_{si})^2+(y_I-y_{si})^2+(z_I-z_{si})^2]^{1/2}+n_{DME} \\ \theta_{VOR_{si}} = tg^{-1}[(y_I-y_{si})/(x_I-x_{si})] + n_{VOR} \end{cases} \tag{3-51}$$

where si symbolizes the distance $r_{DME_{si}}$ or angle $\theta_{VOR_{si}}$ being measured with respect to navigational station i. The measurement noise vector is:

$$\underline{v}_B = [n_v \; n_\alpha \; n_\beta \; n_h \; n_{DME_1} \; n_{DME_2} \cdots n_{VOR_1} \; n_{VOR_2} \ldots]^T \quad (3\text{-}52)$$

Estimates of measurement biases and scale factor errors may be obtained at the expense of significant increase in state vector dimension. Such an increase in dimension may affect not only the computing cost but also the computational accuracy.

Examination of eq. (3-40) to (3-51) shows that both models A and B are nonlinear. Thus the extended Kalman smoother algorithm has to be applied (Ref. 14). This algorithm is implemented as a combination of forward- and backward-running Kalman filters. The extended Kalman filter algorithm constitutes an adaptation of the linear Kalman filter theory to nonlinear situations. It propagates the nonlinear dynamic model between measurements and utilizes a locally linearized model for the measurement updates.

The following is the discrete formulation of the extended Kalman smoother algorithm, applied to the dynamic model of the system, which constitutes of the state model (eq. (3-38)) and measurement model (eq. (3-39)). The propagation of the estimated states $\hat{\underline{x}}$ and of the state covariance matrix P between measurements, for forward filtering uses

$$\dot{\hat{\underline{x}}}(t) = \underline{f}[\hat{\underline{x}}(t), \underline{u}(t)] \quad (3\text{-}53)$$

$$P_k(-) = \Phi_{k-1} P_{k-1}(+) \Phi_{k-1}^T + Q_{k-1} \tag{3-54}$$

where Q is the process noise covariance matrix and Φ is the transition matrix obtained after local linearization of eq. (3-38) into:

$$\dot{\underline{x}} = F\underline{x} + G\underline{u} + L\underline{w} \tag{3-55}$$

In order not to create inaccuracies due to numerical differentiation, analytical derivation of the Jacobian matrices (F, G and L) has been carried out for both models A and B; this is documented in Appendix A. The Kalman gain matrix for forward filtering is,

$$K_k = P_k(-) H_k^T [H_k P_k(-) H_k^T + R_k]^{-1} \tag{3-56}$$

where R is the measurement noise covariance matrix and H is obtained by local linearization of eq. (3-39) as

$$\underline{z}_k = H_k \underline{x} + \underline{v}_k \tag{3-57}$$

State and covariance updates account for measurements as

$$\hat{\underline{x}}_k(+) = \hat{\underline{x}}(t) + K_k [\underline{z}_k - \underline{h}_k(\underline{x}(t))] \tag{3-58}$$

$$P_k(+) = [I - K_k H_k] P_k(-) \tag{3-59}$$

where $\hat{\underline{x}}(t)$ is obtained by integration of eq. (3-53) from t_{k-1} to t_k.

The filter processing of the raw data renders the state estimates before the measurement update $\hat{\underline{x}}_k(-) \equiv \hat{\underline{x}}(t)$ and after the measurement update $\hat{\underline{x}}_k(+)$ and the associated covariance matrices $P_k(-)$ and $P_k(+)$. The smoother algorithm uses this information as input and running backwards in time produces the improved estimates of the states $\hat{\underline{x}}_{k/n}$ and of the covariance matrix $P_{k/n}$. The first step is the computation of the state matrix F_k:

$$F_k = f[\hat{\underline{x}}_k(+)] \tag{3-60}$$

The state matrix is used to calculate the state transition matrix Φ_k. The state transition matrix and the input covariance matrices render matrix A_k:

$$A_k = P_k(+)\Phi_k^T P_{k+1}^{-1}(-) \tag{3-61}$$

Using the input state estimates $\hat{\underline{x}}_k(-)$ and $\hat{\underline{x}}_k(+)$ and the associated covariance matrices $P_k(+)$ and $P_k(-)$ along with A_k, the smoothed and reconstructed states $\hat{\underline{x}}_{k/n}$ are obtained:

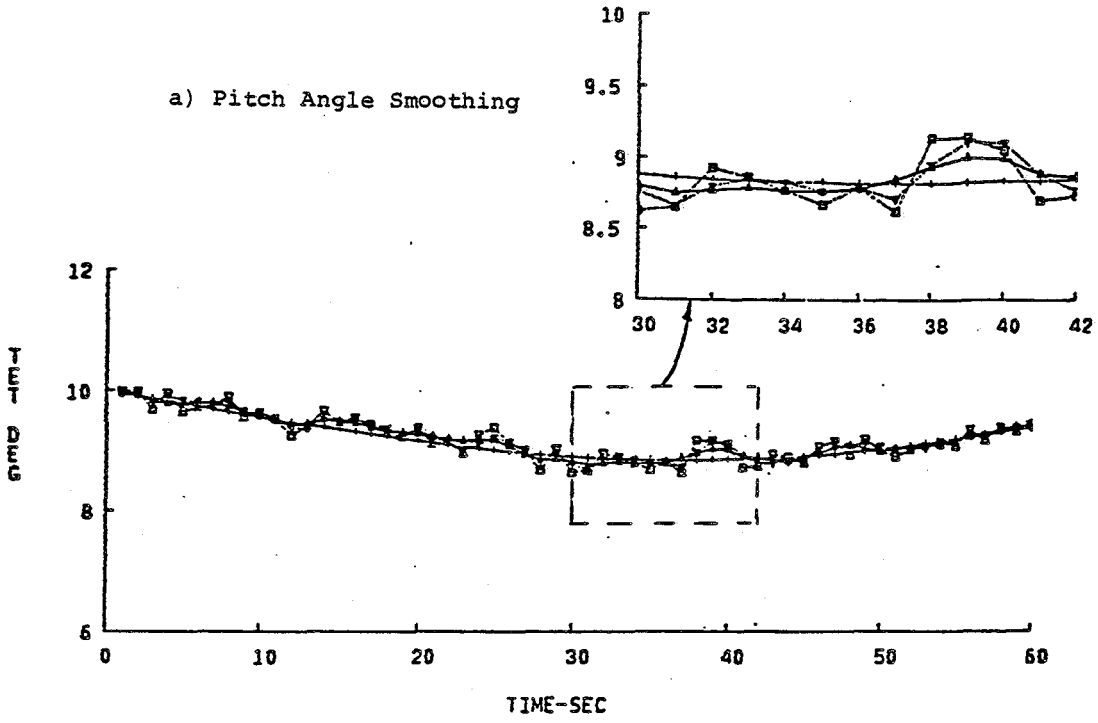
$$\hat{\underline{x}}_{k/n} = \hat{\underline{x}}_k(+) + A_k[\hat{\underline{x}}_{k+1/n} - \hat{\underline{x}}_{k+1}(-)] \tag{3-62}$$

$$P_{k/n} = P_k(+) + A_k[P_{k+1/n} - P_{k+1}(-)]A_k^T \tag{3-63}$$

This complete optimal estimation algorithm, which performs post-flight data smoothing and flight-path reconstruction has been coded in FORTRAN (Appendix B) and verified by application to a computer-generated SPIFR trajectory.

Examples of the optimal flight path reconstruction algorithm's application to the generic flight-test data records are given in Fig. 3-7 for a coordinated climbing turn flight segment of 60 seconds. Figure 3-7a) to f) present reconstructed measurements demonstrating both state variable reconstruction and improvement with respect to data corrupted by noise. The symbol convention used in these figures is: (+) for nominal, (□) for corrupted, (▽) for filtered and (△) for smoothed time histories. Line segments are used to link results but they do not suggest a functional relationship.

Figures 3-7a) and b) represent the optimal smoothing of the angular states. As may have been expected, the "derivative" states (e.g., Fig. 3-7b) are noisier than the "integral" states (e.g., Fig. 3-7a). In a sense, this distinction is applicable to the airspeed versus aerodynamic angle measurements, which reflect the atmospheric turbulence effect. As follows from the translational submodel formulation, to reconstruct these measurements (e.g., Fig. 3-7c) and d)), the states u, v and w are first estimated. The typical lag introduced by filtering is more apparent in some of the figures; it is then reduced by the smoother. The trajectory reconstruction is represented in Fig. 3-7e), f) and g). Note that optimal smoothing improves the filtered state estimates and also shrinks the position uncertainty ellipsoid.



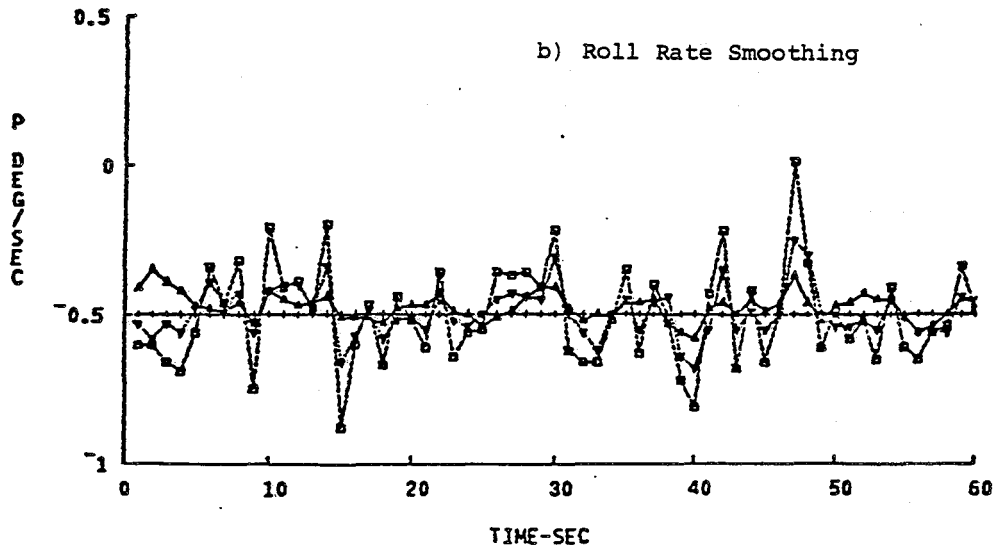
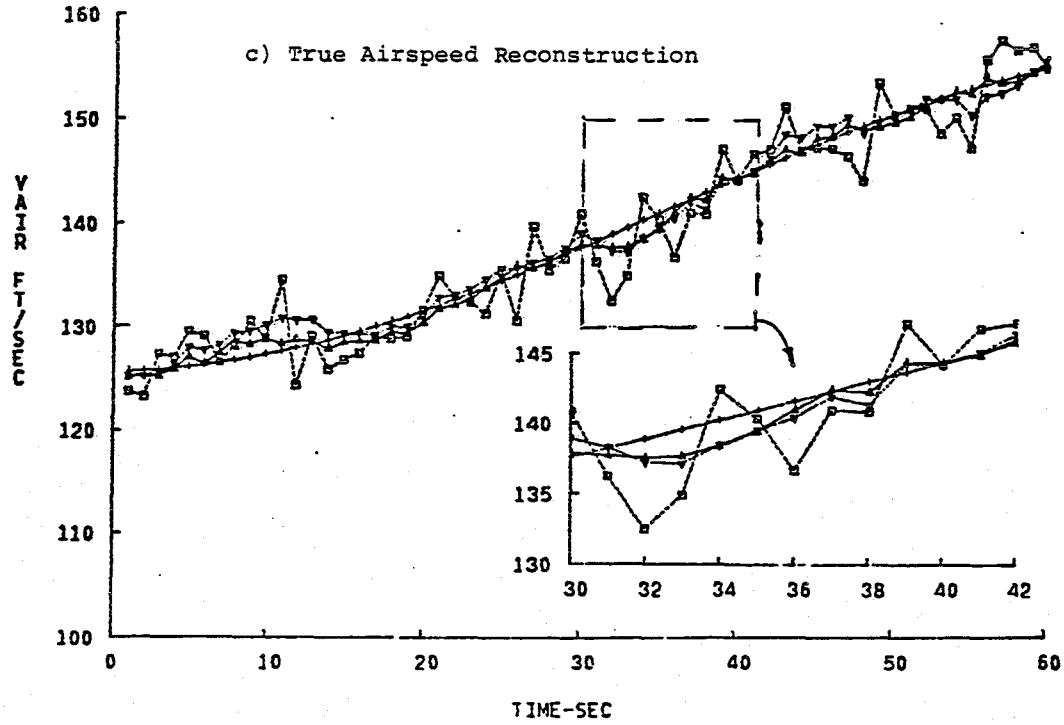


Figure 3-7: Examples of application of the optimal flight path reconstruction algorithm to the climbing turn pseudo-flight-test data.



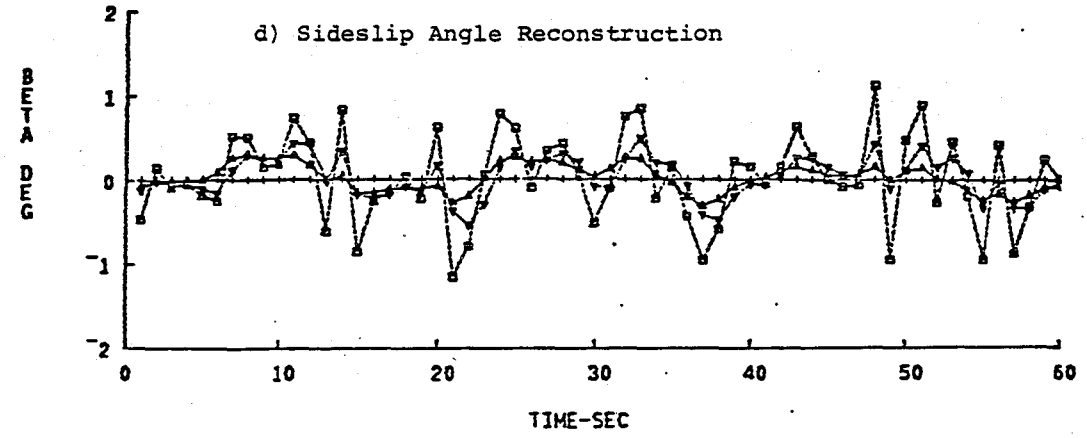


Figure 3-7: (cont.) Examples of application of the optimal flight path reconstruction algorithm to the climbing turn pseudo-flight-test data.

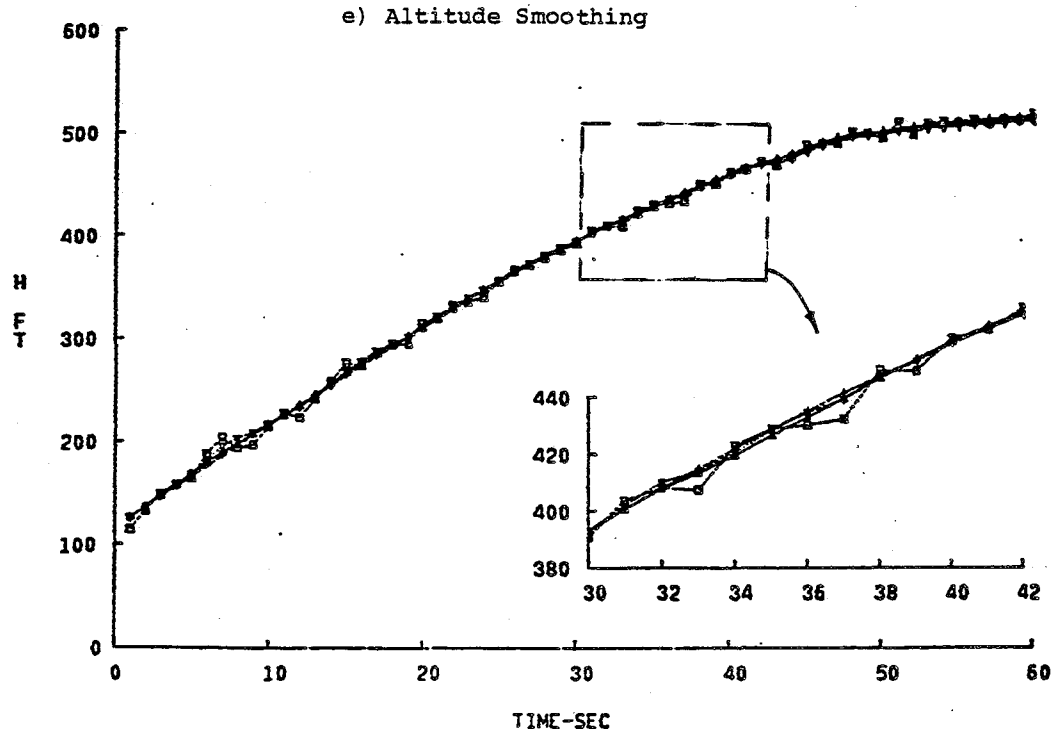
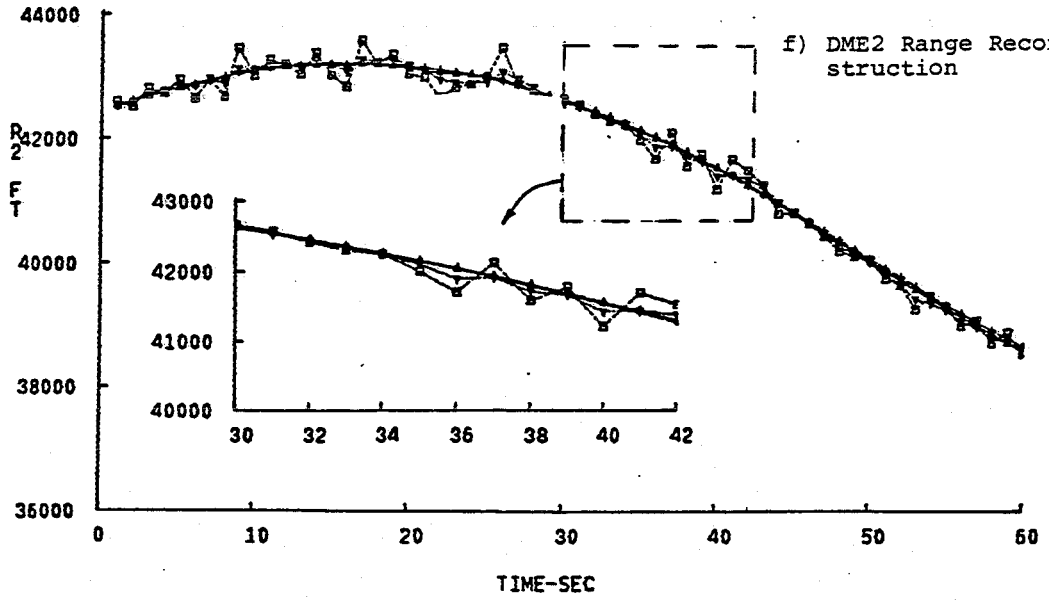


Figure 3-7: (cont.) Examples of application of the optimal flight path reconstruction algorithm to the climbing turn pseudo-flight-test data.



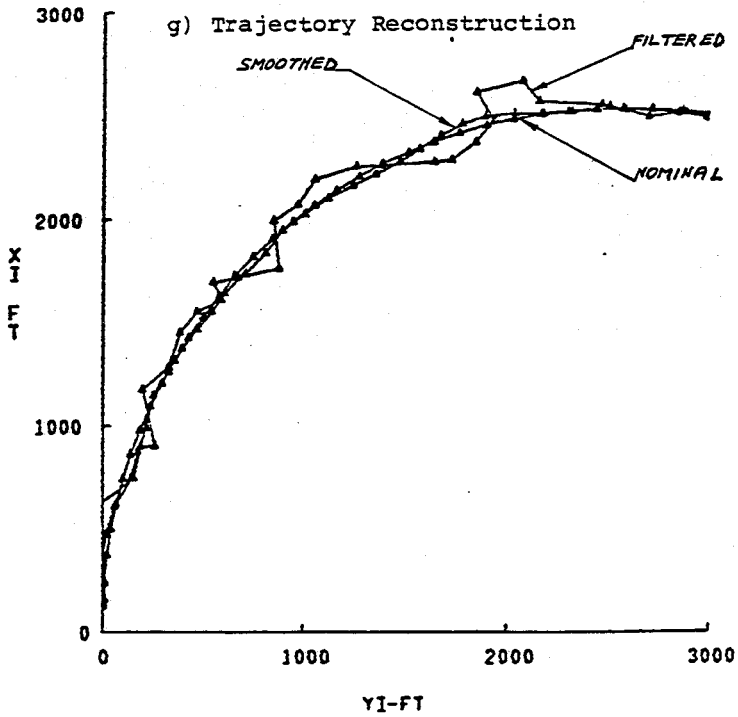


Figure 3-7: (cont.) Examples of application of the optimal flight path reconstruction algorithm to the climbing turn pseudo-flight-test data.

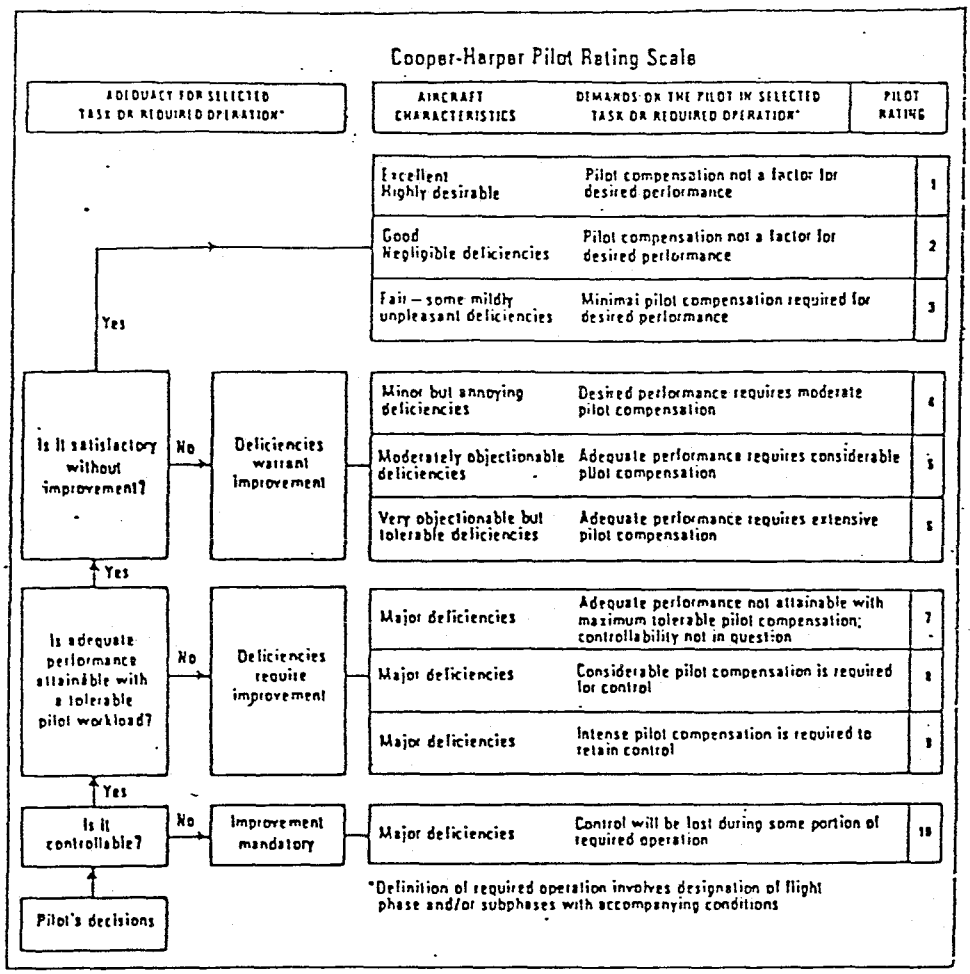
4. PRELIMINARY FLIGHTS

Flight test results are the important objectives of the SPIFR program. As the human operator is an integral part of the control and guidance loop, Pilot Opinion Ratings (POR) constitute important experimental results. Both the Cooper-Harper Rating (CHR), which is a performance rating (Ref. 15) and the workload rating (M.I.T. scale, Ref. 15) are significant. As we debrief the evaluation pilot with regard to both the complete mission and to its specific segments, knee-pad-size versions of both scales and of the grading sheet have been prepared (Fig. 4-1).

To test the complete SPIFR-mission-simulation concept, a series of preliminary flights has been carried out. Its main objectives were to verify the realism of simulation of SPIFR regime environment, the in-flight configuration matching capability and the data acquision and reduction process.

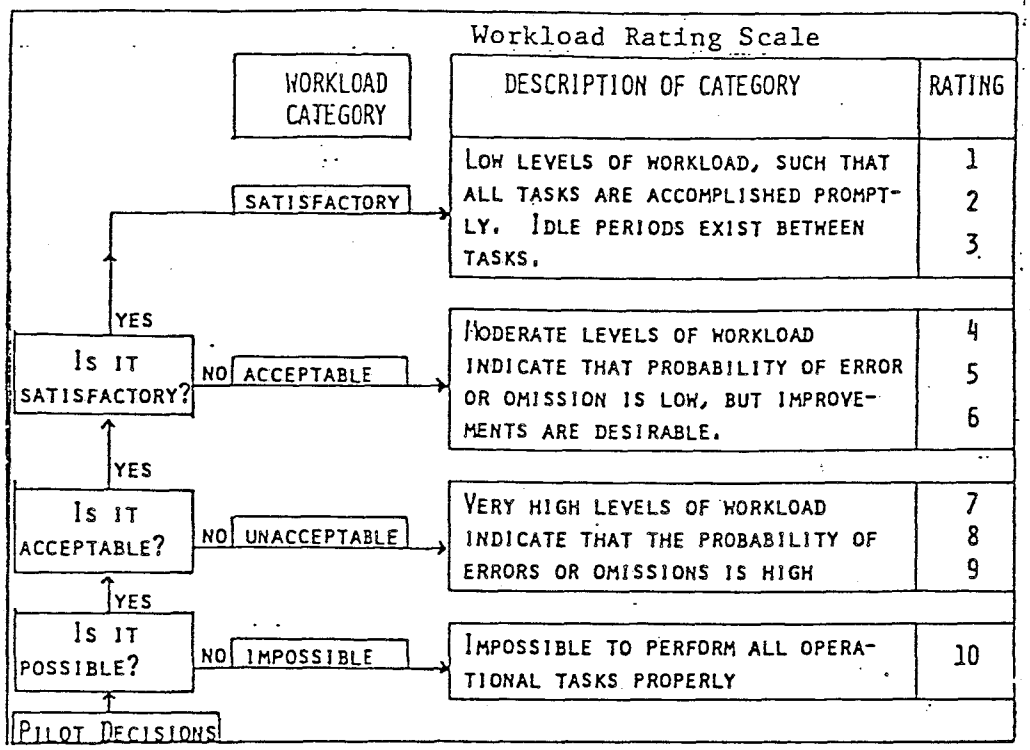
After extensive hangar checks of the aircraft system modifications, of the new navigation/communication package and of the onboard experimental setup, the proposed instrument tracks (Fig. 3-2 to 3-5) were flown - totalling to about 10 flight hours.

These preliminary flights have shown that the tasks appear to simulate SPIFR missions, which are realistic in both geometry and workload. Using the knee-pad-size POR scales and grading sheet the in-flight debriefing can be carried out without interfering with the mission. The in-flight configuration matching capability with regard to each



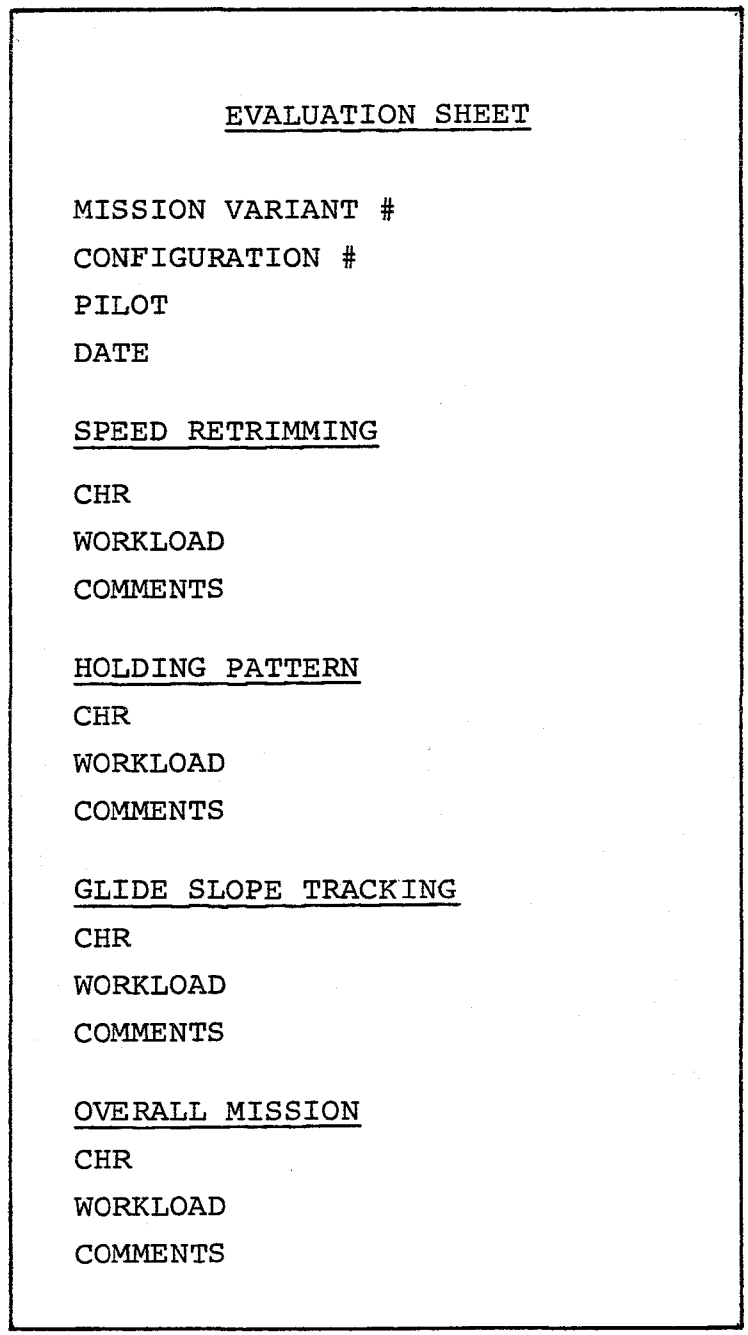
a) Performance POR Scale

Figure 4-1: Knee-pad Versions of the Performance and Workload PORs and of the Evalution Sheet.



b) Workload POR Scale

Figure 4-1: (cont.) Knee-pad Versions of the Performance and Workload PORs and of the Evalution Sheet.



c) Evaluation Sheet.

Figure 4-1: (cont.) Knee-pad Versions of the Performance and Workload PORs and of the Evalution Sheet.

of the priority configurations has been confirmed. The data collection and reduction process has been verified by comparison of timings and directions of deflection of various controls reported by the safety pilot to those obtained by recorded data processing.

5. CONCLUSION

This report summarizes the first phase of the SPIFR project, which constitutes an integrated theoretical and flight-test research effort, which addresses stability-and-control, avionics and human factor effects in single pilot IFR situations. The first phase activities were aimed at basic research system preparation and, consequently, at conducting the first flight test series of the SPIFR four-year program.

Most of the goals of the first phase of the SPIFR program have been achieved. The basic research system has been put together and successfully flight-tested, including the ARA aircraft modifications and the onboard digital data acquisition system. A modern navigation/communication system has been installed, and a new instrument panel has been designed to accomodate flexibility in introduction of additional instrumentation and workload devices. The data collection system has been built around the Z-80 microprocessor. The microprocessor performs the analog channels sampling, preliminary processing and transfer of the data records to the digital recorder. The software required for these on-board manipulations has been developed, debugged and flight-tested. In parallel, the post-flight data preprocessing software and procedure development has been completed and tried out with actual in-flight recorded data. Mission planning and experimental matrix design have been carried out accounting for navigational accuracy and the "learning curve effect" and for the amount-of-flight-hours-constraint. Applying theoretical algorithms the aerodynamic configurations for the

SPIFR program have been obtained and implemented on the ARA aircraft. A preliminary flight-test series has been conducted to check whether realistic SPIFR conditions are obtained and to verify the in-flight configurations matching. These flight tests have confirmed that the SPIFR mission simulation is realistic both in geometry and in workload.

During the second phase of the SPIFR project, the first flight series will be completed and the collected data will be analysed, including the subjective PORs. Finally, statistical regression analysis will be applied to render flying qualities criteria for Single Pilot Instrument Flight Rule operations.

The structure of the research program as summarized in this report will render quantitative criteria with regard to the effects of airframe dynamic response, workload level, and pilot experience on the SPIFR flight regime. Furthermore, the ARA is now ready to conduct a broad range of additional flight experiments associated with single-pilot instrument flight.

APPENDIX A

DERIVATION OF THE LINEARIZED VERSIONS OF THE SIMPLIFIED AND THE IMPROVED KINEMATIC MODELS

A.1 IMPROVED WIND MODEL

The kinematic state model B (eq.(3-50)) assumes that ideal, constant wind measurements $\underline{w}_I$ are available along the flight path. Although we may disregard the high-frequency turbulence disturbances, it is difficult to obtain wind measurements along a flight path with an acceptable degree of reliability. A solution is to adjoin a wind model to state model B, estimating its parameters along with $\underline{x}_B$. A reasonable low-frequency wind model may constitute of a constant component and a linear variation with altitude,

$$\underline{w}_I(h) = \underline{w}_{I_o} + \frac{\partial \underline{w}_I}{\partial z_I}(z_I - z_{I_o}) \qquad \text{(A-1)}$$

where $\underline{w}_{I_o}$ is a constant wind vector at reference altitude $-z_{I_o}$ and $\frac{\partial \underline{w}_I}{\partial z_I}$ is a vector of slope of wind variation with altitude. Adjoining eq. (A-1) to eq. (3-50), we obtain:

$$\begin{bmatrix} \dot{x}_I \\ \dot{y}_I \\ \dot{z}_I \end{bmatrix} = \hat{H}_B^I(t) \begin{bmatrix} u \\ v \\ w \end{bmatrix} + \begin{bmatrix} w_{x_{I_o}} + \frac{\partial w_{x_I}}{\partial z_I}(z_I - z_{I_o}) \\ w_{y_{I_o}} + \frac{\partial w_{y_I}}{\partial z_I}(z_I - z_{I_o}) \\ w_{z_{I_o}} + \frac{\partial w_{z_I}}{\partial z_I}(z_I - z_{I_o}) \end{bmatrix} \qquad \text{(A-2)}$$

$$\begin{bmatrix} \dot{u} \\ \dot{v} \\ \dot{w} \end{bmatrix} = \hat{\hat{\omega}}(t) \begin{bmatrix} u \\ v \\ w \end{bmatrix} + \begin{bmatrix} a_x - s\hat{\theta}\, g \\ a_y + c\hat{\theta}s\hat{\Phi}g \\ a_z + c\hat{\theta}c\hat{\phi}g \end{bmatrix} + \begin{bmatrix} n_{a_x} \\ n_{a_y} \\ n_{a_z} \end{bmatrix} + \hat{H}_I^B(t) * \frac{\partial w_I}{\partial z_I} * [\dot{z}_I] \qquad \text{(A-3)}$$

Carrying through the mathematical steps necessary to transfer the state variable z_I derivative to the left-hand side, we obtain the state model B in the following form:

$$\begin{bmatrix} \dot{x}_I \\ \dot{y}_I \\ \dot{z}_I \end{bmatrix} = \hat{H}_B^I(t) \begin{bmatrix} u \\ v \\ w \end{bmatrix} + \begin{bmatrix} w_{x_{I_o}} + \frac{\partial w_{x_I}}{\partial z_I}(z_I - z_{I_o}) \\ w_{y_{I_o}} + \frac{\partial w_{y_I}}{\partial z_I}(z_I - z_{I_o}) \\ w_{z_{I_o}} + \frac{\partial w_{z_I}}{\partial z_I}(z_I - z_{I_o}) \end{bmatrix} \qquad \text{(A-4)}$$

$$\begin{bmatrix} \dot{u} \\ \dot{v} \\ \dot{w} \end{bmatrix} = \hat{\tilde{\omega}}(t) \begin{bmatrix} u \\ v \\ w \end{bmatrix} + \begin{bmatrix} a_x - s\hat{\theta}\ g \\ a_y + c\hat{\theta}s\hat{\phi}g \\ a_z + c\hat{\theta}c\hat{\phi}g \end{bmatrix} + \begin{bmatrix} n_{a_x} \\ n_{a_y} \\ n_{a_z} \end{bmatrix} + H_{uvw} * \hat{H}^B_I(t) \frac{\partial \underline{w}_I}{\partial z_I} \qquad \text{(A-5)}$$

$$\begin{bmatrix} \dot{w}_{x_{I_o}} \\ \dot{w}_{y_{I_o}} \\ \dot{w}_{z_{I_o}} \end{bmatrix} = \begin{bmatrix} 0 \\ 0 \\ 0 \end{bmatrix} \qquad \text{(A-6)}$$

$$\begin{bmatrix} \dfrac{\partial \dot{w}_{x_I}}{\partial z_I} \\ \dfrac{\partial \dot{w}_{y_I}}{\partial z_I} \\ \dfrac{\partial \dot{w}_{z_I}}{\partial z_I} \end{bmatrix} = \begin{bmatrix} 0 \\ 0 \\ 0 \end{bmatrix} \qquad \text{(A-7)}$$

$$H_{uvw} \triangleq [\hat{H}^I_{B_{31}} \quad \hat{H}^I_{B_{32}} \quad \hat{H}^I_{B_{33}}] \begin{bmatrix} u \\ v \\ w \end{bmatrix} \qquad \text{(A-8)}$$

The kinematic state model B of eq. (A-2) to (A-8) renders improved flight path reconstruction and an estimate of constant wind and of wind gradient along the flight path.

A.2 LINEARIZATION OF THE SIMPLIFIED KINEMATIC MODEL

To apply the extended Kalman filter algorithm the non-linear kinematic model has to be linearized. The linearized version of the simplified kinematic model has been derived analytically and is presented in this section. The result for state model A [eq. (3-40)] is:

$$\begin{bmatrix} \dot{p} \\ \dot{q} \\ \dot{r} \\ \dot{\phi} \\ \dot{\theta} \\ \dot{\psi} \end{bmatrix} = \begin{bmatrix} 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 1 & tg\theta s\phi & tg\theta c\phi & qtg\theta c\phi - rtg\theta s\phi & (qs\phi + rc\phi)/c^2\theta & 0 \\ 0 & c\phi & -s\phi & -qs\phi - rc\phi & 0 & 0 \\ 0 & s\phi/c\theta & c\phi/c\theta & qc\phi/c\theta - rs\phi/c\theta & (qs\phi + rc\phi)\frac{s\theta}{c^2\theta} & 0 \end{bmatrix} \begin{bmatrix} p \\ q \\ r \\ q \\ \theta \\ \psi \end{bmatrix} + \begin{bmatrix} n_p \\ n_q \\ n_r \\ 0 \\ 0 \\ 0 \end{bmatrix} \quad \text{(A-9)}$$

$\dot{\underline{x}}_A \qquad\qquad F_A \qquad\qquad \underline{x}_A \quad \underline{w}_A$

Rearranging eq. (3-50) of state model B:

$$\begin{bmatrix} \dot{x}_I \\ \dot{y}_I \\ \dot{z}_I \\ \dot{u} \\ \dot{v} \\ \dot{w} \end{bmatrix} = \left[\begin{array}{c|c} 0 & \hat{H}_B^I(t) \\ 6x3 & \\ \hline & \hat{\tilde{\omega}}(t) \end{array}\right] \begin{bmatrix} x_I \\ y_I \\ z_I \\ u \\ v \\ w \end{bmatrix} + [I] \begin{bmatrix} w_{x_I} \\ w_{y_I} \\ w_{z_I} \\ a_x - \hat{s\theta}\, g \\ a_y + \hat{c\theta s\Phi} g \\ a_z + \hat{c\Theta c\Phi} g \end{bmatrix} + \begin{bmatrix} 0 \\ 0 \\ 0 \\ n_{a_x} \\ n_{a_y} \\ n_{a_z} \end{bmatrix} \quad \text{(A-10)}$$

$\dot{\underline{x}}_B \qquad F_B \qquad \underline{x}_B \quad G_B \qquad \underline{u}_B \qquad \underline{w}_B$

The linearized version of measurement model B [eq. (3-51)]:

$$\underbrace{\begin{bmatrix} |\underline{v}_{air}| \\ \alpha \\ \beta \\ h \\ r_{DME_{s1}} \\ r_{DME_{s2}} \\ \theta_{VOR_{s1}} \\ \theta_{VOR_{s2}} \end{bmatrix}}_{\underline{z}_B} = \underbrace{\begin{bmatrix} 0 & 0 & 0 & \frac{u}{a_o^{1/2}} & \frac{v}{a_o^{1/2}} & \frac{w}{a_o^{1/2}} \\ 0 & 0 & 0 & \frac{-w}{a_o - v^2} & 0 & \frac{u}{a_o - v^2} \\ 0 & 0 & 0 & \frac{-v}{a_o - w^2} & \frac{u}{a_o - w^2} & 0 \\ 0 & 0 & -1 & 0 & 0 & 0 \\ \frac{x_I - x_{s1}}{a_{31}^{1/2}} & \frac{y_I - y_{s1}}{a_{31}^{1/2}} & \frac{z_I - z_{s1}}{a_{31}^{1/2}} & 0 & 0 & 0 \\ \frac{x_I - x_{s2}}{a_{32}^{1/2}} & \frac{y_I - y_{s2}}{a_{32}^{1/2}} & \frac{z_I - z_{s2}}{a_{32}^{1/2}} & 0 & 0 & 0 \\ \frac{-(y_I - y_{s1})}{a_{31} - (z_I - z_{s1})^2} & \frac{x_I - x_{s1}}{a_{31} - (z_I - z_{s1})^2} & 0 & 0 & 0 & 0 \\ \frac{-(y_I - y_{s2})}{a_{32} - (z_I - z_{s2})^2} & \frac{x_I - x_{s2}}{a_{32} - (z_I - z_{s2})^2} & 0 & 0 & 0 & 0 \end{bmatrix}}_{H_B} \underbrace{\begin{bmatrix} x_I \\ y_I \\ z_I \\ u \\ v \\ w \end{bmatrix}}_{\underline{x}_B} + \underbrace{\begin{bmatrix} n_v \\ n_\alpha \\ n_\beta \\ n_h \\ n_{DME_1} \\ n_{DME_2} \\ n_{VOR_1} \\ n_{VOR_2} \end{bmatrix}}_{\underline{v}_B} \quad \text{(A-11)}$$

$$\text{with:} \quad a_o = u^2 + v^2 + w^2$$
$$a_{3i} = (x_I - x_{si})^2 + (y_I - y_{si})^2 + (z_I - z_{si})^2 \quad \text{(A-12)}$$

A.3 LINEARIZATION OF THE IMPROVED KINEMATIC MODEL.

The improvement to the kinematic model elaborated in the first section of this appendix refers to state model B. The linearized version of (A-3) is:

$$
\begin{bmatrix}
\dot{x}_I \\ \dot{y}_I \\ \dot{z}_I \\ \dot{u} \\ \dot{v} \\ \dot{w} \\ \dot{w}_{x_{I_o}} \\ \dot{w}_{y_{I_o}} \\ \dot{w}_{y_{I_o}} \\ \frac{\partial \dot{w}_{x_I}}{\partial z_I} \\ \frac{\partial \dot{w}_{y_I}}{\partial z_I} \\ \frac{\partial \dot{w}_{z_I}}{\partial z_I}
\end{bmatrix}
=
\begin{bmatrix}
 & & & \\ & & & \\ & & & \\ & & & \\ F_{11} & F_{12} & F_{13} & F_{14} \\ F_{21} & F_{22} & F_{23} & F_{24} \\ & & & \\ F_{31} & F_{32} & F_{33} & F_{34} \\ & & & \\ & & & \\ F_{41} & F_{42} & F_{43} & F_{44} \\ & & &
\end{bmatrix}
\begin{bmatrix}
x_I \\ y_I \\ z_I \\ u \\ v \\ w \\ w_{x_{I_o}} \\ w_{y_{I_o}} \\ w_{z_{I_o}} \\ \frac{\partial w_{x_I}}{\partial z_I} \\ \frac{\partial w_{y_I}}{\partial z_I} \\ \frac{\partial w_{z_I}}{\partial z_I}
\end{bmatrix}
+
\begin{bmatrix}
0 \\ 0 \\ 0 \\ a_x - s\theta g \\ a_y + c\hat{\theta}s\hat{\phi}g \\ a_z + c\hat{\theta}c\hat{\phi}g \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0
\end{bmatrix}
+
\begin{bmatrix}
0 \\ 0 \\ 0 \\ n_{a_x} \\ n_{a_y} \\ n_{a_z} \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0
\end{bmatrix}
\qquad \text{(A-13)}
$$

$\dot{\underline{x}}_B$ $\quad F_B \quad$ $\underline{x}_B$

where each F_{ij} stands for a 3x3 matrix:

$$F_{21} = F_{31} = F_{41} = F_{32} = F_{42} = F_{23} = F_{33} = F_{43} = F_{34} = F_{44} = [0] \tag{A-14}$$

$$F_{13} = [I] \tag{A-15}$$

$$F_{14} = (z_I - z_{I_o})[I] \tag{A-16}$$

$$F_{11} = \begin{bmatrix} 0 & 0 & \frac{\partial w_{x_I}}{\partial z_I} \\ 0 & 0 & \frac{\partial w_{y_I}}{\partial z_I} \\ 0 & 0 & \frac{\partial w_{z_I}}{\partial z_I} \end{bmatrix} \tag{A-17}$$

$$F_{12} = \hat{H}^I_B(t) \tag{A-18}$$

$$F_{22} = \begin{bmatrix} \hat{H}^I_{B_{31}}\left(\hat{H}^B_I \frac{\partial \underline{w}_I}{\partial z_I}\right)_1 & \hat{r}+\hat{H}^I_{B_{32}}\left(\hat{H}^B_I \frac{\partial \underline{w}_I}{\partial z_I}\right)_1 & -\hat{q}+\hat{H}^I_{B_{33}}\left(\hat{H}^B_I \frac{\partial \underline{w}_I}{\partial z_I}\right)_1 \\ -\hat{r}+\hat{H}^I_{B_{31}}\left(\hat{H}^B_I \frac{\partial \underline{w}_I}{\partial z_I}\right)_2 & \hat{H}^I_{B_{32}}\left(\hat{H}^B_I \frac{\partial \underline{w}_I}{\partial z_I}\right)_2 & \hat{p}+\hat{H}^I_{B_{33}}\left(\hat{H}^B_I \frac{\partial \underline{w}_I}{\partial z_I}\right)_2 \\ \hat{q}+\hat{H}^I_{B_{31}}\left(\hat{H}^B_I \frac{\partial \underline{w}_I}{\partial z_I}\right)_3 & -\hat{p}+\hat{H}^I_{B_{32}}\left(\hat{H}^B_I \frac{\partial \underline{w}_I}{\partial z_I}\right)_3 & \hat{H}^I_{B_{33}}\left(\hat{H}^B_I \frac{\partial \underline{w}_I}{\partial z_I}\right)_3 \end{bmatrix} \tag{A-19}$$

$$F_{24} = H_{uvw} * \hat{H}^B_I(t) \tag{A-20}$$

APPENDIX B

PROGRAM LISTINGS

B.1 ONBOARD ASSEMBLY PROGRAMMING

The microprocessor prepares the data in block units. Each block unit is a memory buffer of 1024 data words (each data word contains two bytes or 16 bits). For 38 information channels, for example, taken every second such a block can be filled with 26-sec worth of data (plus 36 dummy words: 38x26+36 = 1024). A data block is written into the digital cartridge recordwise. Each record contains 128 data words, i.e., under normal conditions eight records complete a block transfer. Occasionally, to make sure that no data is missed, a record may be written repeatedly onto the cartridge. Thus, the first task for the preprocessing software (Appendix C) is to reconstruct the original data blocks, each constituting of eight records of $\frac{8x128-36}{38}$ = 26 information-seconds.

B.2 GENERIC SPIFR FLIGHT PATH AND IN-FLIGHT MEASUREMENTS SIMULATION (FORTRAN)

This program creates a generic SPIFR mission trajectory, simulates the associated in-flight measurements and corrupts them with pseudo-random noise. Knowing the uncorrupted values of the measured variables, the algorithm for optimal smoothing and flight path reconstruction may be verified.

B.3 OPTIMAL SMOOTHING AND FLIGHT PATH RECONSTRUCTION ALGORITHM (FORTRAN)

As demonstrated in the following listings, one of the key issues in optimal smoothing and flight path reconstruction is computer storage management -- in particular, between the forward and the backward passes over the measured data records. The smoothing algorithm, which consists of eq. (3-60) to (3-63), requires knowledge of the state-vector before and after each measurement update and of the corresponding covariance matrices. For state model A, e.g., the state vector has six components. This means that following the filtering pass 84 values have to be stored for each measurement instant. A SPIFR mission simulation is about 30 minutes long and after preprocessing the measurement update interval is standardized to be 1 sec for all variables. Thus, the temporary storage facility has to "remember" 84x30x60 values.

```
                    1   ;
                    2   ;               VERSION 8 SPIFFER  18.V.81
                    3   ;               ADC READ, PUSHBUTTONS, BLINKING LIGHTS WORKING
                    4   ;               DISPLAY MEMORY INCLUDED
                    5   ;               TAPES INSTALLED
                    6   ;               DATA AVERAGING IMPLEMENTED
                    7   ;               SLOW CHANNELS AVERAGED AT CNT = 4
                    8   ;               DME TO BE IMPLEMENTED AS SLOW CHANNEL
                    9   ;               ADC CHANNEL ZERO READ TWICE TO FILL OPEN RAM SLOT
                   10   ;               LEFT BY MOVING DME TO SLOW CHANNEL.
                   11   ;               STILL AVERAGING OVER 12 FAST CHANNELS.
                   12   ;               HAVE A BUFFER OF 38 WORDS (16 BITS WIDE)
                   13   ;               INSTEAD OF 37 WORDS.
                   14   ;               HAVE FOUR LIGHTS INSTEAD OF THREE
                   15   ;               LIGHT4 IS IN SYNC WITH LIGHT3.
                   16   ;               THE LIGHTS CODING IS ALL NEW.
                   17   ;
8000               18           ORG     8000H
3000               19   ADDAM   EQU     3000H      ;ADDRESS OF A TO D CONVERTER
00C3               20   JMP     EQU     0C3H
                   21   ;C0      EQU     03BH
FFE3               22   INT75   EQU     0FFE3H
00C5               23   LITEPORT EQU     0C5H       ;LITE DISPLAY PORT IS PORT C J1 OF 116 BOARD
00C7               24   LITECTRL EQU     0C7H       ;CTRL PORT FOR J1 OF 116 BOARD
                   25   ;LITEPORT EQU     0E9H       ;LITE DISPLAY PORT IS PORT B J2 OF 8004
                   26   ;LITECTRL EQU     0EBH       ;CTRL PORT FOR J2 OF 8004
00E7               27   J18004  EQU     0E7H       ;CONTROL OF 8255 J-1
00E4               28   ALTPORT EQU     0E4H       ;ALTIMETER PORT A J-1
00E5               29   PUSHPORT EQU     0E5H       ;PUSHBUTTON PORT B J-1
8000  F3           30           DI                 ;NO INTERRUPTS ALLOWED YET
8001  CD738A       31           CALL    INITPORTA  ;8255 PORT A OF J2 ON 8004
8004  CD2188       32           CALL    INITUSART  ;INITIALISE THE USART FOR PILOT TERMINAL
8007  CD3787       33           CALL    INITSEMA   ;SET UP SEMAPHORES ON ALL TEN BUFFERS
800A  CDBC87       34           CALL    INITRE
800D  CD4080       35           CALL    FILLMEM    ;FILL MEMORY WITH INTEGERS 0-10239
8010  CDD480       36           CALL    INITWR     ;INITIALISE EMPTYING POINTERS
                   37                              ;DUMP TEN BUFFERS EACH 2048
                   38                              ;TO TAPE, 256 BYTES AT A TIME
                   39                              ;OVER AND OVER AGAIN.
                   40                              ;THE BUFFERS ARE DESIGNATED BY
                   41                              ; THE DIGITS 0 TO 9.
                   42                              ;
                   43                              ;DE POINTS TO THE LOCATION
                   44                              ; TO BE EMPTIED.
                   45                              ;
8013  CD118A       46           CALL    ALIGN      ;INITALISE T9511
8016  CD2A8A       47           CALL    OK
8019  110090       48           LXI     D,BUFF0    ;DE PAIR POINT TO LOCATION TO BE EMPTIED
801C  CD3883       49           CALL    STINT      ;ENABLE THE INTERRUPTS
                   50   BB:
801F  CD7687       51           CALL    TSTEMPTY   ;WAIT UNTIL BUFFER FULL
8022  CDA180       52           CALL    WRITE      ;DUMP ANOTHER 256 BYTES TO TAPE
8025  CD5880       53           CALL    UEBUFS     ;UPDATE THE INDICES USED
                   54                              ; TO KEEP TRACK OF EMPTYING THE TEN BUFFERS.
                   55                              ;  THERE ARE THREE OF THEM,
                   56                              ;   TWO POINTERS AND A COUNTER.
                   57                              ;
8028  C31F80       58           JMP     BB
                   59                              ;
802B  3A6188       60           LDA     FLAG
802E  FE00         61           CPI     0
8030  C21F80       62           JNZ     BB
8033  3E0A         63           MVI     A,10
```

```
;;8035 326188        64              STA     FLAG
;;8038 3E24          65              MVI     A,'$'
;;803A CD4182        66              CALL    BO
;;803D C31F80        67              JMP     BB
;;                  68      ;LAG:   DB      0
;;                  69      FILLMEM:
;;8040 F5            70              PUSH    PSW
;;8041 E5            71              PUSH    H
;;8042 110090        72              LXI     D,BUFF0 ;BASE ADDRESS FOR FILLING IS BUFF0
;;8045 210000        73              LXI     H,0     ;COUNT STARTS WITH 0
;;8048 7D            74      FILLAG: MOV     A,L     ;LOWER BYTE INTO ACC
;;8049 12            75              STAX    D       ;SOTRE IT TO MEMORY
;;804A 13            76              INX     D       ;MOVE TO NEXT BYTE LOCATION
;;804B 7C            77              MOV     A,H     ;UPPER BYTE INTO ACC
;;804C 12            78              STAX    D       ;STORE IT TO MEMORY
;;804D 13            79              INX     D       ;POINT TO NEXT BYTE LOCATION
;;804E 23            80              INX     H       ;SIZE OF INTEGER UP BY 1
;;804F 7C            81              MOV     A,H     ;CHECK FOR AN UPPER BOUND
;;8050 FE28          82              CPI     28H     ;
;;8052 C24880        83              JNZ     FILLAG  ;REPEAT IF BELOW UPPER BOUND
;;8055 E1            84              POP     H
;;8056 F1            85              POP     PSW
;;8057 C9            86              RET
;;                  87      UEBUFS:
;;8058 F5            88              PUSH    PSW
;;8059 E5            89              PUSH    H
;;805A C5            90              PUSH    B
;;805B 2A6688        91              LHLD    EREMAIN
;;805E 010001        92              LXI     B,256   ;256 BYTES EMPYIED AT A TIME
;;8061 AF            93              XRA     A       ;CARRY=0
;;8062 ED42          94              DSBC    B
;;8064 226688        95              SHLD    EREMAIN ;EREMAIN=EREMAIN-256
;;                  96                              ;
;;                  97                              ;IS EREMAIN >= 256 ?
;;                  98                              ;
;;8067 AF            99              XRA     A       ;CARRY=0
;;8068 ED42         100              DSBC    B
;;806A F29D80       101              JP      EROOM   ;IF S=0, HL >= BC
;;                 102                              ;
;;                 103                              ;CAN NOT EMPTY
;;                 104                              ; ANOTHER BLOCK OF 256
;;                 105                              ;  FROM CURRENT BUFFER OF 2048
;;                 106                              ;
;;806D CDA887       107              CALL    SETEMPTY ;MARK CURRENT BUFFER EMPTY
;;                 108                              ;SET UP INDICES FOR DUMPING NEXT 2048 BLOCK
;;8070 210008       109              LXI     H,2048  ;
;;8073 226688       110              SHLD    EREMAIN ;EREMAIN=2048
;;                 111                              ;
;;8076 3A6888       112              LDA     EWHICHB ;SWITCH TO NEXT BUFFER
;;8079 3C           113              INR     A       ;
;;807A 326888       114              STA     EWHICHB ;
;;807D FE0A         115              CPI     10
;;807F C29280       116              JNZ     ESW     ;
;;8082 76           117              HLT
;;                 118                              ;
;;                 119                              ;WE ARE NOW BEYOND TENTH BUFFER
;;                 120                              ; NOTE EWHICHB HAS RANGE 0 TO 9
;;                 121                              ;  SWITCH TO BUFFER 0
;;                 122                              ;
;;8083 3E00         123              MVI     A,0
;;8085 326888       124              STA     EWHICHB ;EWHICH=0
;;                 125                              ;
;;                 126                              ;ECURRBUF CONTAINS THE STARTING
;;                 127                              ; LOCATION OF THE CURRENT 2048 BLOCK
;;                 128                              ;  BEING EMPTYIED
;;                 129                              ;
```

```
¿¿8088  110090          130             LXI     D,BUFF0   ;BUFF0 IS STARTING LOCATION OF
¿¿                      131                               ; BLOCK 0 OR BUFFER 0
¿¿808B  ED537488        132             SDED    ECURRBUF  ;NOTE THAT DE POINTS WHERE ECURRBUF POINTS
¿¿808F  C39D80          133             JMP     EROOM
¿¿                      134     ESW:
¿¿                      135                               ;
¿¿                      136                               ;WE ARE GOING TO EMPTY A BUFFER
¿¿                      137                               ; 2048 BYTES HIGHER IN CORE THAN THE
¿¿                      138                               ;  PREVIOUS BUFFER.
¿¿                      139                               ;
¿¿8092  2A7488          140             LHLD    ECURRBUF  ;
¿¿8095  010008          141             LXI     B,2048
¿¿8098  09              142             DAD     B
¿¿8099  227488          143             SHLD    ECURRBUF
¿¿809C  EB              144             XCHG              ;DE POINTING WHERE ECURRBUF POINTS.
¿¿                      145     EROOM:
¿¿809D  C1              146             POP     B
¿¿809E  E1              147             POP     H
¿¿809F  F1              148             POP     PSW
¿¿80A0  C9              149             RET
¿¿                      150     ;
¿¿                      151     WRITE:
¿¿                      152                               ;THE ONLY ERROR ALLOWED FOR NOW
¿¿                      153                               ;IS TRYING TO WRITE BEYOND EOT
¿¿                      154                               ;WRITE ON LEFT TAPE OR RIGHT TAPE
¿¿                      155                               ;DEPENDING ON THE SETTING OF TSW
¿¿                      156                               ;TSW='L' OR 'R'.
¿¿                      157                               ;IF END OF TAPE OR HARD ERROR ON ONE TAPE,
¿¿                      158                               ;SWITCH TO ANOTHER TAPE
¿¿                      159                               ;
¿¿80A1  F5              160             PUSH    PSW
¿¿80A2  E5              161             PUSH    H
¿¿80A3  C5              162             PUSH    B
¿¿80A4  ED537888        163             SDED    TEMPDE    ;SAVE DE PAIR IN CASE OF RETRY
¿¿                      164     ;       LXI     H,TEMPDE
¿¿                      165     ;       CALL    HDMP2
¿¿80A8  3A6988          166             LDA     TSW       ;WHICH TAPE DO WE USE?
¿¿80AB  FE4C            167             CPI     'L'
¿¿80AD  C2C280          168             JNZ     WRITR
¿¿                      169     WRITL:
¿¿80B0  CD3481          170             CALL    LCTUM     ;IF YOU COME TO EOT SWITCH TO NEXT UNIT
¿¿                      171     ;((((((((((MORE CODE HERE))))))))))))))))))
¿¿                      172     ;((((((((((ABOUT SWITCHING LOGIC))))))))))))
¿¿80B3  CABE80          173             JZ      RETWL
¿¿80B6  3E52            174             MVI     A,'R'
¿¿80B8  326988          175             STA     TSW
¿¿                      176     ;((((((((((RETRANSMIT LAST RECORD ONTO RIGHT TAPE))))))))))))
¿¿80BB  C3C280          177             JMP     WRITR     ; AND REWRITE RECORD ON RIGHT TAPE
¿¿80BE  C1              178     RETWL:  POP     B
¿¿80BF  E1              179             POP     H
¿¿80C0  F1              180             POP     PSW
¿¿80C1  C9              181             RET
¿¿                      182     WRITR:
¿¿80C2  CDD581          183             CALL    RCTUM     ;IF YOU COME TO EOT SWITCH TO NEXT UNIT
¿¿                      184     ;(((((((MORE CODE HERE)))))))))))))))))))))))
¿¿                      185     ;(((((((ABOUT SWITCHING LOGIC)))))))))))))))))
¿¿80C5  CAD080          186             JZ      RETWR
¿¿80C8  3E4C            187             MVI     A,'L'
¿¿80CA  326988          188             STA     TSW
¿¿                      189     ;(((((((RETRANSMIT LAST RECORD USING)))))))))))
¿¿80CD  C3B080          190             JMP     WRITL     ; AND REWRITE RECORD ON LEFT TAPE
¿¿80D0  C1              191     RETWR:  POP     B
¿¿80D1  E1              192             POP     H
¿¿80D2  F1              193             POP     PSW
¿¿80D3  C9              194             RET
¿¿                      195     INITWR:
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00D4  F5          196           PUSH    PSW
00D5  E5          197           PUSH    H
00D6  3E00        198           MVI     A,0
00D8  326888      199           STA     EWHICHB
00DB  210008      200           LXI     H,2048
00DE  226688      201           SHLD    EREMAIN
00E1  3E4C        202           MVI     A,'L'
00E3  326988      203           STA     TSW
00E6  210090      204           LXI     H,BUFF0
00E9  227488      205           SHLD    ECURRBUF
00EC  110090      206           LXI     D,BUFF0
00EF  E1          207           POP     H
00F0  F1          208           POP     PSW
00F1  C9          209           RET
              210   DEM256:
00F2  E5          211           PUSH    H
              212                                   ;
              213                                   ;DE (= DE - 256
              214                                   ;
00F3  62          215           MOV     H,D
00F4  6B          216           MOV     L,E       ;HL (= DE
00F5  010001      217           LXI     B,256
00F8  AF          218           XRA     A         ;CARRY=0
00F9  ED42        219           DSBC    B         ;HL - 256
00FB  54          220           MOV     D,H
00FC  5D          221           MOV     E,L       ;DE (= HL
00FD  E1          222           POP     H
00FE  C9          223           RET
              224   LCTUF:
              225                                   ;WRITE AN EOF MARK ON LCTU
00FF  3E1B        226           MVI     A,ESC
0101  CD4182      227           CALL    BO
0104  3E26        228           MVI     A,'&'
0106  CD4182      229           CALL    BO
0109  3E70        230           MVI     A,'p'
010B  CD4182      231           CALL    BO
010E  3E31        232           MVI     A,'1'     ;ADDRESS OF LCTU
0110  CD4182      233           CALL    BO
0113  3E75        234           MVI     A,'u'
0115  CD4182      235           CALL    BO
0118  3E35        236           MVI     A,'5'     ;WRITE FILEMARK COMMAND IS  ASCII CHAR 5
011A  CD4182      237           CALL    BO
011D  3E43        238           MVI     A,'C'
011F  CD4182      239           CALL              BO
0122  3E11        240           MVI     A,DC1
0124  CD4182      241           CALL    BO
0127  CD5782      242           CALL    BI
012A  326288      243           STA     SAVE
012D  CD5782      244           CALL    BI
0130  326388      245           STA     SAVE+1
0133  C9          246           RET
              247   LCTUW:
0134  ED5B7888    248           LDED    TEMPDE
0138  3E1B        249           MVI     A,ESC
013A  CD4182      250           CALL    BO
013D  3E26        251           MVI     A,'&'
013F  CD4182      252           CALL    BO
0142  3E70        253           MVI     A,'p'
0144  CD4182      254           CALL    BO
0147  3E31        255           MVI     A,'1'
0149  CD4182      256           CALL    BO
014C  3E64        257           MVI     A,'d'
014E  CD4182      258           CALL    BO
0151  3E32        259           MVI     A,'2'
0153  CD4182      260           CALL    BO
0156  3E35        261           MVI     A.'5'
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8158 CD4182      262          CALL    BO
815B 3E36        263          MVI     A,'6'
815D CD4182      264          CALL    BO
8160 3E57        265          MVI     A,'W'
8162 CD4182      266          CALL    BO
8165 3E05        267          MVI     A,ENQ
8167 CD4182      268          CALL    BO
816A CD5782      269          CALL    BI
816D 326488      270          STA     SAV
8170 FE06        271          CPI     ACK
8172 CA7881      272          JZ      NEXT
8175 C33481      273          JMP     LCTUM
                 274  NEXT:                        ;DE POINTS TO LOCATION TO BE EMPTIED
8178 010001      275          LXI     B,256
817B CD7482      276          CALL    SEND
817E 3E11        277          MVI     A,DC1
8180 CD4182      278          CALL    BO
8183 CD5782      279          CALL    BI           ;READ S OF F
8186 DA3481      280          JC      LCTUM
8189 326288      281          STA     SAVE
818C CD5782      282          CALL    BI           ;READ CR
818F DA3481      283          JC      LCTUM
8192 326388      284          STA     SAVE+1
8195 3A6288      285          LDA     SAVE         ;EITHER S OR F
8198 FE53        286          CPI     'S'
819A C8          287          RZ                   ;RETURN Z SET ON 'S', Z RESET ON 'F'
819B ED5B7888    288          LDED    TEMPDE
819F C9          289          RET
                 290  RCTUF:
                 291                               ;WRITE AN EOF MARK ON LCTU
81A0 3E1B        292          MVI     A,ESC
81A2 CD4182      293          CALL    BO
81A5 3E26        294          MVI     A,'&'
81A7 CD4182      295          CALL    BO
81AA 3E70        296          MVI     A,'p'
81AC CD4182      297          CALL    BO
81AF 3E32        298          MVI     A,'2'        ;ADDRESS OF RCTU
81B1 CD4182      299          CALL    BO
81B4 3E75        300          MVI     A,'u'
81B6 CD4182      301          CALL    BO
81B9 3E35        302          MVI     A,'5'        ;WRITE FILEMARK COMMAND IS  ASCII CHAR 5
81BB CD4182      303          CALL    BO
81BE 3E43        304          MVI     A,'C'
81C0 CD4182      305          CALL                 BO
81C3 3E11        306          MVI     A,DC1
81C5 CD4182      307          CALL    BO
81C8 CD5782      308          CALL    BI
81CB 326288      309          STA     SAVE
81CE CD5782      310          CALL    BI
81D1 326388      311          STA     SAVE+1
81D4 C9          312          RET
                 313  RCTUM:
81D5 ED5B7888    314          LDED    TEMPDE
81D9 3E1B        315          MVI     A,ESC
81DB CD4182      316          CALL    BO
81DE 3E26        317          MVI     A,'&'
81E0 CD4182      318          CALL    BO
81E3 3E70        319          MVI     A,'p'
81E5 CD4182      320          CALL    BO
81E8 3E32        321          MVI     A,'2'        ;ADDRESS OF RCTU
81EA CD4182      322          CALL    BO
81ED 3E64        323          MVI     A,'d'
81EF CD4182      324          CALL    BO
81F2 3E32        325          MVI     A,'2'
81F4 CD4182      326          CALL    BO
81F7 3E35        327          MVI     A,'5'
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81F9 CD4182      328          CALL    BO
81FC 3E36        329          MVI     A,'6'
81FE CD4182      330          CALL    BO
8201 3E57        331          MVI     A,'W'
8203 CD4182      332          CALL    BO
8206 3E05        333          MVI     A,ENQ
8208 CD4182      334          CALL    BO
820B CD5782      335          CALL    BI
820E 326488      336          STA     SAV
8211 FE06        337          CPI     ACK
8213 CA1982      338          JZ      NEXT
8216 C3D581      339          JMP     RCTUN
                 340  NEXT:
                 341                                  ;DE POINTS TO LOCATION TO BE EMPTIED
8219 010001      342          LXI     B,256
821C CD7482      343          CALL    SEND
821F 3E11        344          MVI     A,DC1
8221 CD4182      345          CALL    BO
8224 CD5782      346          CALL    BI          ; READ S OR F
8227 DAD581      347          JC      RCTUN
822A 326288      348          STA     SAVE
822D CD5782      349          CALL    BI          ; READ CR
8230 DAD581      350          JC      RCTUN
8233 326388      351          STA     SAVE+1
8236 3A6288      352          LDA     SAVE        ;EITHER S OR F
8239 FE53        353          CPI     'S'         ;RETURN WITH Z SET ON S, Z RESET ON F
823B C8          354          RZ
823C ED5B7888    355          LDED    TEMPDE
8240 C9          356          RET
                 357  ;*****************************************************
                 358  ;                 CHARACTER OUTPUT ROUTINE
                 359  ; CO OUTPUTS ONE CHARACTER FROM ACC TO TERMINAL
                 360  ; VIA THE USART. ALL REGISTERS AND FLAGS ARE
                 361  ; PRESERVED. THE CHARACTER  IT OUTPUTS IS IN THE ACC.
                 362  ;*****************************************************
8241 F5          363  BO:     PUSH    PSW
8242 C5          364          PUSH    B
8243 4F          365          MOV     C,A         ;SAVE A REG
                 366  BOO:
8244 00          367          NOP
8245 00          368          NOP
8246 DBED        369          IN      S8251A      ;GET USART STATUS
8248 E601        370          ANI     TXRDYA      ;CHECK TRANSMIT READY FLAG
824A CA4482      371          JZ      BOO         ;NOT READY
824D 00          372          NOP
824E 00          373          NOP
824F 00          374          NOP
8250 00          375          NOP
8251 79          376          MOV     A,C         ;READY TO TRANSMIT , RESTORE CHAR TO A REG
8252 D3EC        377          OUT     D8251A      ;SEND IT
8254 C1          378          POP     B
8255 F1          379          POP     PSW
8256 C9          380          RET
                 381  ;*****************************************************
                 382  ;                 CHARACTER INPUT ROUTINE
                 383  ; BI INPUTS ONE CHARACTER FROM TERMINAL INTO ACC
                 384  ; VIA THE USART. THE  FLAGS AND THE ACC ARE CHANGED.
                 385  ; THE CHARACTER IT READS IS RETURNED IN THE ACC.
                 386  ;  IF NO TIMEOUT OCCURS, THE CARRY IS SET.
                 387  ;  IF TIMEOUT OCCURS, THE CARRY IS RESET.
                 388  ;  THE CHAR READ IS RETURNED IN THE ACC.
                 389  ;*****************************************************
8257 00          390  BI:     NOP             ;
8258 C5          391          PUSH    B
8259 01FFFF      392          LXI     B,0FFFFH
                 393  BIO:
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;;825C 0B          394          DCX     B
;;825D 78          395          MOV     A,B
;;825E B1          396          ORA     C
;;825F CA6F82      397          JZ      TIMEOUT
;;8262 DBED        398          IN      S8251A    ;GET USART STATUS
;;8264 E602        399          ANI     RXRDYA    ;CHECK RECIEVER READY
;;8266 CA5C82      400          JZ      BIO       ;
;;8269 DBEC        401          IN      D8251A    ;GET CHAR
;;826B 37          402          STC
;;826C 3F          403          CMC
;;826D C1          404          POP     B
;;826E C9          405          RET
;;826F 00          406 TIMEOUT: NOP
;;8270 37          407          STC
;;8271 C1          408          POP     B
;;8272 C9          409          RET
;;8273 76          410          HLT
;;                 411 SEND:
;;8274 1A          412          LDAX    D
;;8275 CD4182      413          CALL    BO
;;8278 13          414          INX     D
;;8279 0B          415          DCX     B
;;827A 78          416          MOV     A,B
;;827B B1          417          ORA     C
;;827C C27482      418          JNZ     SEND
;;827F C9          419          RET
;;                 420 STATUS:
;;8280 F5          421          PUSH    PSW
;;8281 E5          422          PUSH    H
;;8282 21FC89      423          LXI     H,STAT
;;8285 3E1B        424          MVI     A,ESC     ;START ESCAPE SEQUENCE
;;8287 CD4182      425          CALL    BO
;;828A 3E5E        426          MVI     A,'^'
;;828C CD4182      427          CALL    BO
;;828F 3E11        428          MVI     A,DC1
;;8291 CD4182      429          CALL    BO
;;8294 CD5782      430          CALL    BI        ;EAT ESC
;;8297 CD5782      431          CALL    BI        ;EAT BACLSLASH
;;829A CD5782      432          CALL    BI        ;BYTE 0
;;829D CD0B88      433          CALL    CO
;;82A0 CD5782      434          CALL    BI        ;BYTE 1
;;82A3 CD0B88      435          CALL    CO
;;82A6 CD5782      436          CALL    BI        ;BYTE 2
;;82A9 CD0B88      437          CALL    CO
;;82AC CD5782      438          CALL    BI        ;BYTE 3
;;82AF CD0B88      439          CALL    CO
;;82B2 CD5782      440          CALL    BI        ;BYTE 4
;;82B5 CD0B88      441          CALL    CO
;;82B8 CD5782      442          CALL    BI        ;BYTE 5
;;82BB CD0B88      443          CALL    CO
;;82BE CD5782      444          CALL    BI        ;BYTE 6
;;82C1 CD0B88      445          CALL    CO
;;82C4 CD5782      446          CALL    BI        ;GET CR
;;82C7 CD0B88      447          CALL    CO
;;82CA E1          448          POP     H
;;82CB F1          449          POP     PSW
;;82CC C9          450          RET
;;                 451 LCTUST:
;;82CD F5          452          PUSH    PSW
;;82CE E5          453          PUSH    H
;;82CF 3E1B        454          MVI     A,ESC
;;82D1 CD0B88      455          CALL    CO
;;82D4 3E26        456          MVI     A,'&'
;;82D6 CD0B88      457          CALL    CO
;;82D9 3E70        458          MVI     A,'p'
;;82DB CD0B88      459          CALL    CO
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82DE 3E31      460          MVI   A,'1'
82E0 CD0B88    461          CALL  CO
82E3 3E5E      462          MVI   A,'^'
82E5 CD0B88    463          CALL  CO
82E8 3E11      464          MVI   A,DC1
82EA CD0B88    465          CALL  CO
82ED CD5782    466          CALL  BI       ;ESC READ
82F0 CD5782    467          CALL  BI       ;BACKSLASH READ
82F3 CD5782    468          CALL  BI       ;P READ
82F6 CD5782    469          CALL  BI       ;DEVICE CODE DIGIT READ
82F9 CD5782    470          CALL  BI       ;BYTE 0 READ
82FC CD5782    471          CALL  BI       ;BYTE 1 READ
82FF CD5782    472          CALL  BI       ;BYTE 2 READ
8302 CD5782    473          CALL  BI       ;CR READ
8305 E1        474          POP   H
8306 F1        475          POP   PSW
8307 C9        476          RET
               477  ;
               478  ;                     DELAY ONE MILLISECOND
               479  ;
               480  D1MS:
8308 C5        481          PUSH  B
8309 F5        482          PUSH  PSW
830A 019800    483          LXI   B,152
830D 0B        484  D1MS0:   DCX   B
830E 78        485          MOV   A,B
830F B1        486          ORA   C
8310 C20D83    487          JNZ   D1MS0
8313 F1        488          POP   PSW
8314 C1        489          POP   B
8315 C9        490          RET
001B           491  ESC     EQU   1BH
000D           492  CR      EQU   0DH
00ED           493  S8251A  EQU   0EDH
00EC           494  D8251A  EQU   0ECH
0002           495  RXRDYA  EQU   02H
0001           496  TXRDYA  EQU   01H
000A           497  LF      EQU   0AH
0005           498  ENQ     EQU   05H
0006           499  ACK     EQU   06H
0011           500  DC1 EQU 11H
8316 F5        501  CNTR1:  PUSH  PSW
8317 3E74      502          MVI   A,074H
8319 D3DF      503          OUT   0DFH
831B 3E10      504          MVI   A,TLOW
831D D3DD      505          OUT   0DDH
831F 3E27      506          MVI   A,THIGH
8321 D3DD      507          OUT   0DDH
8323 E3        508          XTHL
8324 E3        509          XTHL
8325 F1        510          POP   PSW
8326 C9        511          RET
8327 F5        512  CNTR0:  PUSH  PSW
8328 3E36      513          MVI   A,036H
832A D3DF      514          OUT   0DFH
832C 3E0A      515          MVI   A,0AH
832E D3DC      516          OUT   0DCH
8330 3E00      517          MVI   A,00H
8332 D3DC      518          OUT   0DCH
8334 E3        519          XTHL
8335 E3        520          XTHL
8336 F1        521          POP   PSW
8337 C9        522          RET
               523  STIMT:
8338 F5        524          PUSH  PSW
8339 E5        525          PUSH  H
```

```
                        526     ;
                        527     ;               PUT 'JMP BREAK' INST. AT LOCS INT75,INT75+1,INT75+2
                        528     ;
033A  3EC3              529             MVI     A,JMP
033C  32E3FF            530             STA     INT75
033F  214F83            531             LXI     H,BREAK
0342  22E4FF            532             SHLD    INT75+1
                        533     ;
                        534     ;               SETUP 8214 INTERRUPT CONTROOLER
                        535     ;
0345  3E03              536             MVI     A,03H       ;BIT 7=0 FOR MODE 0
                        537                                 ;BIT 0 TO 3 DEFINE INTERRUPT PRIORIRY
                        538                                 ;BIT 0 TO 3 SET TO 3, ENABLE 2 TO 0 ONLY
0347  D307              539             OUT     0D7H        ; SEND TO 8214
                        540     ;
                        541     ;;              PUT Z80 IN INTERRUPT MODE 0
                        542     ;
0349  ED46              543             IM0
034B  E1                544             POP     H
034C  F1                545             POP     PSW
                        546     ;
                        547     ;               TURN ON INTERRUPT SYSTEM
                        548     ;
034D  FB                549             EI
034E  C9                550             RET
                        551     ;
                        552     ;               COME HERE ON TIMER INTERRUPT
                        553     ;
034F  00                554     BREAK:  NOP
0350  F5                555             PUSH    PSW
0351  E5                556             PUSH    H
0352  C5                557             PUSH    B
0353  D5                558             PUSH    D
                        559     ;
0354  3A6188            560             LDA     FLAG
0357  3D                561             DCR     A
0358  326188            562             STA     FLAG
                        563     ;
035B  3EFF              564             MVI     A,0FFH      ;MAKE OUTPUT OF
035D  D3E8              565             OUT     0E8H        ;   ZERO VOLTS
035F  ED5B5788          566             LDED    SAVEDE      ;RESTORE BUFFER POINTER TO DE PAIR
0363  CD4A87            567             CALL    TSTFULL     ;IS BUFFER EMPTY
                        568     ;
                        569     ;               IF CNT)=0.AND. CNT(=9 READ FAST CHANS AND STORE
                        570     ;
0366  CDC383            571             CALL    FAST        ;COLLECT FAST DATA
                        572     ;
                        573     ;               IF CNT = 4 READ SLOW CHANNELS
                        574     ;
0369  3A5E88            575             LDA     CNT
036C  FE04              576             CPI     4
036E  C27483            577             JNZ     NOT4
0371  CD2484            578             CALL    SLOW
                        579     NOT4:
                        580     ;
                        581     ;
                        582     ;               IF CNT=9 READ TIME AND SLOW CHANS
                        583     ;
0374  3A5E88            584             LDA     CNT         ;
0377  FE09              585             CPI     9           ;
0379  C2A783            586             JNZ     NOT9        ;
                        587     ;
037C  213400            588             LXI     H,2*26
037F  19                589             DAD     D           ;ADD 2*26 TO DE PAIR TO POINT BEYOND
0380  5D                590             MOV     E,L
0381  54                591             MOV     D,H         ;PUT HL IN DE
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;;83A2 CDCA86      592          CALL    DISPLAY  ;IF THERE IS TWODIG PAIR READY, DISPLAY MEMORY
;;83A5 CDF484      593          CALL    UPBUFS   ;THERE ARE TWO BUFER POINTERS AND COUNTER
;;                 594                           ;  TO UPDATE
;;83A8 CD5785      595          CALL    UCLK     ;TIC THE CLOCK
;;83AB CD4D86      596          CALL    FLIP     ;TOGGLE LITE 3
;;83AE CD7A88      597          CALL    AVG
;;83B1 CD3D85      598          CALL    UINTS
;;83B4 CD4785      599          CALL    RINTS
;;83B7 ED535788    600          SDED    SAVEDE
;;83BB AF          601          XRA     A
;;83BC D3E8        602          OUT     0E8H
;;83BE CD9785      603          CALL    STATE
;;83A1 CD7886      604          CALL    INTWODIG
;;83A4 C3B983      605          JMP     NODISP
;;                 606     ;
;;                 607     NOT9:
;;                 608          ;
;;83A7 CD7A88      609          CALL    AVG      ;AVERAGE FAST CHANNELS
;;83AA CD3D85      610          CALL    UINTS    ;UPDATE INTERRUPT COUNT
;;                 611     ;
;;83AD CD4785      612          CALL    RINTS    ;RESET INTERRUPT COUNT WHEN NECESSARY
;;83B0 AF          613          XRA     A        ;MAKE OUTPUT OF
;;83B1 D3E8        614          OUT     0E8H     ;  FIVE VOLTS
;;                 615     ;
;;                 616     ;
;;83B3 CD9785      617           CALL   STATE    ; PLAY WITH PBS + LITES ON CONTROL PANEL
;;83B6 CD7886      618          CALL    INTWODIG ;LOOK FOR FOR TWO DIGIT PAIR
;;                 619     NODISP:
;;83B9 3E03        620           MVI    A,03H
;;83BB D3D7        621           OUT    0D7H
;;83BD D1          622          POP     D
;;83BE C1          623          POP     B
;;83BF E1          624          POP     H
;;83C0 F1          625          POP     PSW
;;83C1 FB          626          EI
;;83C2 C9          627          RET
;;                 628     FAST:
;;83C3 3E00        629          MVI     A,0
;;83C5 CD6185      630          CALL    ADC0
;;83C8 CDEB84      631          CALL    STORE
;;                 632     ;
;;83CB 3E00        633          MVI     A,0      ;DELE COLUMN CHANNEL .
;;83CD CD6185      634          CALL    ADC0     ;  READ ADC CHANNEL
;;83D0 CDEB84      635          CALL    STORE    ;    PUT IN BUFFER RAM
;;                 636     ;
;;83D3 3E05        637          MVI     A,5      ;THETADOT CHANNEL
;;83D5 CD6185      638          CALL    ADC0     ;  READ ADC CHANNEL
;;83D8 CDEB84      639          CALL    STORE    ;    PUT IN BUFFER RAM
;;                 640     ;
;;83DB 3E07        641          MVI     A,7      ;NZ-NORMAL ACCEL CHANNEL
;;83DD CD6185      642          CALL    ADC0     ;  READ ADC CHANNEL
;;83E0 CDEB84      643          CALL    STORE    ;    PUT IN RAM BUFFER
;;                 644     ;
;;83E3 3E08        645          MVI     A,8      ;DELA-ROOLL WHEEL
;;83E5 CD6185      646          CALL    ADC0     ;  READ ADC CHANNEL
;;83E8 CDEB84      647          CALL    STORE    ;    PUT IN RAM BUFFER
;;                 648     ;
;;83EB 3E09        649          MVI     A,9      ;DELR-PEDALS CHANNEL
;;83ED CD6185      650          CALL    ADC0     ;  READ ADC CHANNEL
;;83F0 CDEB84      651          CALL    STORE    ;    PUT IN RAM BUFFER
;;                 652     ;
;;83F3 3E0B        653          MVI     A,11     ;BETA-SIDESLIP CHANNEL
;;83F5 CD6185      654          CALL    ADC0     ;  READ ADC CHANNEL
;;83F8 CDEB84      655          CALL    STORE    ;    PUT IN RAM BUFFER
;;                 656     ;
;;83FB 3E0D        657          MVI     A,13     ;P-ROLL RATE CHANNEL
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¿¿83FD CD6185      658          CALL    ADC0    ;  READ ADC CHANNEL
¿¿8400 CDEB84      659          CALL    STORE   ;    PUT IN RAM BUFFER
¿¿                 660  ;
¿¿8403 3E0E        661          MVI     A,14    ;R-YAW RATE CHANNEL
¿¿8405 CD6185      662          CALL    ADC0    ;  READ ADC CHANNEL
¿¿8408 CDEB84      663          CALL    STORE   ;    PUT IN RAM BUFFER
¿¿                 664  ;
¿¿840B 3E0F        665          MVI     A,15    ;NY-LATERAL ACCEL CHANNEL
¿¿840D CD6185      666          CALL    ADC0    ;  READ ADC CHANNEL
¿¿8410 CDEB84      667          CALL    STORE   ;    PUT IN RAM BUFFER
¿¿                 668  ;
¿¿8413 3E15        669          MVI     A,21    ;NX-LONGITUDINAL ACCEL CHANNEL
¿¿8415 CD6185      670          CALL    ADC0    ;  READ ADC CHANNEL
¿¿8418 CDEB84      671          CALL    STORE   ;    PUT IN RAM BUFFER
¿¿                 672  ;
¿¿841B 3E19        673          MVI     A,25    ;ALPHA-ANGLE OF ATTACK CHANNEL
¿¿841D CD6185      674          CALL    ADC0    ;  READ ADC CHANNEL
¿¿8420 CDEB84      675          CALL    STORE   ;    PUT IN RAM BUFFER
¿¿8423 C9          676          RET
¿¿                 677  SLOW:
¿¿                 678  ;
¿¿8424 CD7E85      679          CALL    DME     ;DME DISTANCE
¿¿8427 CDEB84      680          CALL    STORE   ;  PUT IN BUFFER RAM
¿¿                 681  ;
¿¿842A 3E01        682          MVI     A,1     ;DELT-THROTTLE HANDLE
¿¿842C CD6185      683          CALL    ADC0    ;  READ ADC CHANNEL
¿¿842F CDEB84      684          CALL    STORE   ;    PUT IN RAM BUFFER
¿¿                 685  ;
¿¿8432 3E02        686          MVI     A,2     ;DELF-FLAP LEVER CHANNEL
¿¿8434 CD6185      687          CALL    ADC0    ;  READ ADC CHANNEL
¿¿8437 CDEB84      688          CALL    STORE   ;    PUT IN RAM BUFFER
¿¿                 689  ;
¿¿843A 3E03        690          MVI     A,3     ;DELET-ELEVATOR TRIM CHANNEL
¿¿843C CD6185      691          CALL    ADC0    ;  READ ADC CHANNEL
¿¿843F CDEB84      692          CALL    STORE   ;    PUT IN RAM BUFFER
¿¿                 693  ;
¿¿8442 3E04        694          MVI     A,4     ;THETA-PITCH ANGLE CHANNEL
¿¿8444 CD6185      695          CALL    ADC0    ;  READ ADC CHANNEL
¿¿8447 CDEB84      696          CALL    STORE   ;    PUT IN RAM BUFFER
¿¿                 697  ;
¿¿844A 3E06        698          MVI     A,6     ;V-VELOCITY CHANNEL
¿¿844C CD6185      699          CALL    ADC0    ;  READ ADC CHANNEL
¿¿844F CDEB84      700          CALL    STORE   ;    PUT IN RAM BUFFER
¿¿                 701  ;
¿¿8452 3E0A        702          MVI     A,10    ;PSI-HEADING ANGLE CHANNEL
¿¿8454 CD6185      703          CALL    ADC0    ;  READ ADC CHANNEL
¿¿8457 CDEB84      704          CALL    STORE   ;    PUT IN RAM BUFFER
¿¿                 705  ;
¿¿845A 3E0C        706          MVI     A,12    ;PHI-ROLL ANGLE CHANNEL
¿¿845C CD6185      707          CALL    ADC0    ;  READ ADC CHANNEL
¿¿845F CDEB84      708          CALL    STORE   ;    PUT IN RAM BUFFER
¿¿                 709  ;
¿¿8462 3E10        710          MVI     A,16    ;DELRT-RUDDER TRIM CHANNEL
¿¿8464 CD6185      711          CALL    ADC0    ;  READ ADC CHANNEL
¿¿8467 CDEB84      712          CALL    STORE   ;    PUT IN RAM BUFFER
¿¿                 713  ;
¿¿846A 3E11        714          MVI     A,17    ;DELAT-AILERON TRIM CHANNEL
¿¿846C CD6185      715          CALL    ADC0    ;  READ ADC CHANNEL
¿¿846F CDEB84      716          CALL    STORE   ;    PUT IN RAM BUFFER
¿¿                 717  ;
¿¿8472 3E12        718          MVI     A,18    ;DELE-ELEVATOR POSITION CHANNEL
¿¿8474 CD6185      719          CALL    ADC0    ;  READ ADC CHANNEL
¿¿8477 CDEB84      720          CALL    STORE   ;    PUT IN RAM BUFFER
¿¿                 721  ;
¿¿847A 3E13        722          MVI     A,19    ;DELT-THROTTLE POSTION CHANNEL
¿¿847C CD6185      723          CALL    ADC0    ;  READ ADC CHANNEL
```

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;;847F CDEB84          724             CALL    STORE   ;   PUT IN RAM BUFFER
;;                    725     ;
;;8482 3E14            726             MVI     A,20    ;DELF-FLAP POSIYION CHANNEL
;;8484 CD6185          727             CALL    ADC0    ; READ ADC CHANNEL
;;8487 CDEB84          728             CALL    STORE   ;   PUT IN RAM BUFFER
;;                    729     ;
;;848A 3E16            730             MVI     A,22    ;DELA-AILERON POSITION CHANNEL
;;848C CD6185          731             CALL    ADC0    ; READ ADC CHANNEL
;;848F CDEB84          732             CALL    STORE   ;   PUT IN RAM BUFFER
;;                    733     ;
;;8492 3E17            734             MVI     A,23    ;DELR-RUDDER POSITION CHANNEL
;;8494 CD6185          735             CALL    ADC0    ; READ ADC CHANNEL
;;8497 CDEB84          736             CALL    STORE   ;   PUT IN RAM BUFFER
;;                    737     ;
;;849A 3E18            738             MVI     A,24    ;N1LOC-N1 LOCALISER CHANNEL
;;849C CD6185          739             CALL    ADC0    ; READ ADC CHANNEL
;;849F CDEB84          740             CALL    STORE   ;   PUT IN RAM BUFFER
;;                    741     ;
;;84A2 3E1A            742             MVI     A,26    ;ALPHAP-PORT ALPHA CHANNEL
;;84A4 CD6185          743             CALL    ADC0    ; READ ADC CHANNEL
;;84A7 CDEB84          744             CALL    STORE   ;   PUT IN RAM BUFFER
;;                    745     ;
;;84AA 3E1B            746             MVI     A,27    ;ALPHAS-STARBOARD ALPHA CHANNEL
;;84AC CD6185          747             CALL    ADC0    ; READ ADC CHANNEL
;;84AF CDEB84          748             CALL    STORE   ;   PUT IN RAM BUFFER
;;                    749     ;
;;84B2 3E1C            750             MVI     A,28    ;LOCMLS-MLS LOCALIZER CHANNEL
;;84B4 CD6185          751             CALL    ADC0    ; READ ADC CHANNEL
;;84B7 CDEB84          752             CALL    STORE   ;   PUT IN RAM BUFFER
;;                    753     ;
;;84BA 3E1D            754             MVI     A,29    ;GSMLS-MLS GLIDE SLOPE CHANNEL
;;84BC CD6185          755             CALL    ADC0    ; READ ADC CHANNEL
;;84BF CDEB84          756             CALL    STORE   ;   PUT IN RAM BUFFER
;;                    757     ;
;;84C2 3E1E            758             MVI     A,30    ;LOCN2-N2 LOCALIZER CHANNEL
;;84C4 CD6185          759             CALL    ADC0    ; READ ADC CHANNEL
;;84C7 CDEB84          760             CALL    STORE   ;   PUT IN RAMBUFER
;;                    761     ;
;;84CA 3E1F            762             MVI     A,31    ;IDELF-FLAP COMMAND CHANNEL
;;84CC CD6185          763             CALL    ADC0    ; READ ADC CHANNEL
;;84CF CDEB84          764             CALL    STORE   ;   PUT IN RAM BUFFER
;;                    765     ;
;;84D2 CD8385          766             CALL    DIGH    ;H
;;84D5 CDEB84          767             CALL    STORE   ;   PUT IN RAM BUFFER
;;                    768     ;
;;84D8 CD8985          769             CALL    DIGLI   ;LIGHTS
;;84DB CDEB84          770             CALL    STORE   ;   PUT IN RAM BUFFER
;;                    771     ;
;;84DE CD8D85          772             CALL    DIGMOD  ;MODE SWITCHES
;;84E1 CDEB84          773             CALL    STORE   ;   PUT IN RAM BUFFER
;;                    774     ;
;;84E4 CD9385          775             CALL    DIGTIM  ;TIME
;;84E7 CDEB84          776             CALL    STORE   ;   PUT IN RAM BUFFER
;;84EA C9              777             RET
;;                    778     STORE:
;;                    779     ;
;;                    780     ;
;;                    781     ;                       TAKE CONTENTS OF HL REGISTER
;;                    782     ;                       STORE AT DOUBLE  BYTE POINTED
;;                    783     ;                       TO BY DE REGISTER.
;;                    784     ;
;;84EB F5              785             PUSH    PSW
;;84EC 7D              786             MOV     A,L
;;84ED 12              787             STAX    D
;;84EE 13              788             INX     D
;;84EF 7C              789             MOV     A,H
```

```
;;84F0 12          790          STAX    D
;;84F1 13          791          INX     D
;;84F2 F1          792          POP     PSW
;;84F3 C9          793          RET
;;                794  ;
;;                795  ;
;;                796  UFBUFS:
;;                797  ;
;;                798  ;
;;                799  ;
;;                800  ;               THERE ARE TWO POINTERS
;;                801  ;               AND ONE COUNTER
;;                802  ;               TO BE UPDATED WHEN CURRENT
;;                803  ;               BUFFER IS FULL.
;;                804  ;
;;                805  ;              FWHICHB IS FROM 0 TO 9
;;                806  ;               AND INDICATES THE CURRENT BUFFER
;;                807  ;               BEING FILLED
;;                808  ;
;;                809  ;               SAVE POINTS TO THE BYTE OF
;;                810  ;               THE CURRENT BUFFER TO BE FILLED
;;                811  ;
;;                812  ;               REMAIN CONTAINS THE NUMBER
;;                813  ;               OF UNFILLED BYTES IN CURRENT BUFFER
;;                814  ;
;;84F4 F5          815          PUSH    PSW
;;84F5 E5          816          PUSH    H
;;84F6 C5          817          PUSH    B
;;84F7 2A5988      818          LHLD    REMAIN    ;
;;84FA 014C00      819          LXI     B,BYTPERSEC     ;BYTPERSEC BYTES FILLED PER SECOND
;;84FD AF          820          XRA     A         ;CARRY=0
;;84FE ED42        821          DSBC    B
;;8500 225988      822          SHLD    REMAIN    ;REMAIN=REMAIN-BYTPERSEC
;;                823  ;
;;                824  ;                         IS REMAIN >= BYTPERSEC
;;                825  ;
;;8503 AF          826          XRA     A         ;CARRY=0
;;8504 ED42        827          DSBC    B
;;8506 F23985      828          JP      ROOM      ;IF S=0, HL >= BC
;;                829  ;
;;                830  ;
;;                831  ;                         CAN NOT FIT
;;                832  ;                         ANOTHER BLOCK OF BYTPERSEC BYTES
;;                833  ;                         IN CURRENT BUFFER
;;                834  ;
;;8509 CD9487      835          CALL    SETFULL   ;MARK CURRENT BUFFER FULL
;;                836  ;
;;850C 210008      837          LXI     H,2048
;;850F 225988      838          SHLD    REMAIN    ;REMAIN=2048
;;                839  ;
;;8512 3A5B88      840          LDA     FWHICHB   ;SWITCH TO NEXT BUFFER
;;8515 3C          841          INR     A         ;
;;8516 325B88      842          STA     FWHICHB   ;
;;8519 FE0A        843          CPI     10
;;851B C22D85      844          JNZ     SW
;;                845  ;
;;                846  ;        HLT
;;851E 3E00        847          MVI     A,0
;;8520 325B88      848          STA     FWHICHB
;;8523 110090      849          LXI     D,BUFF0
;;8526 ED537688    850          SDED    CURRBUF
;;852A C33985      851          JMP     ROOM
;;                852  ;
;;852D 2A7688      853  SW:     LHLD    CURRBUF   ;BASE ADDRESS OF CURRENT BUFFER
;;8530 010008      854          LXI     B,2048
;;8533 09          855          DAD     B         ; INCREMENT BY 2048
```

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2534  227688    856          SHLD    CURRBUF   ;UPDATED BASE ADDRESS SAVED
2537  54        857          MOV     D,H       ;AND PUT INTO
2538  5D        858          MOV     E,L       ;  THE DE PAIR
              859  ;
              860  ROOM:
2539  C1        861          POP     B
253A  E1        862          POP     H
253B  F1        863          POP     PSW
253C  C9        864          RET
              865  UINTS:
253D  F5        866          PUSH    PSW
253E  3A5E88    867          LDA     CNT
2541  3C        868          INR     A
2542  325E88    869          STA     CNT
2545  F1        870          POP     PSW
2546  C9        871          RET
              872  RINTS:
2547  F5        873          PUSH    PSW
2548  3A5E88    874          LDA     CNT
254B  FE0A      875          CPI     10
254D  C25585    876          JNZ     NOT10
2550  3E00      877          MVI     A,0
2552  325E88    878          STA     CNT
              879  NOT10:
2555  F1        880          POP     PSW
2556  C9        881          RET
              882  UCLK:
2557  E5        883          PUSH    H
2558  2A5C88    884          LHLD    TIM
255B  23        885          INX     H
255C  225C88    886          SHLD    TIM
255F  E1        887          POP     H
2560  C9        888          RET
              889  ADC0:
2561  320130    890          STA     ADDAH+01H
2564  3E01      891          MVI     A,01
2566  320030    892          STA     ADDAH+00H
2569  3A0030    893  BUSY    LDA     ADDAH+00H
256C  07        894          RLC
256D  D26925    895          JNC     BUSY
2570  2A0430    896          LHLD    ADDAH+04H
2573  C9        897          RET
              898  CDC0:
2574  6F        899          MOV     L,A
              900  ;
2575  2600      901          MVI     H,0
2577  C9        902          RET
              903  BDC0:
2578  6F        904          MOV     L,A
2579  3A5E88    905          LDA     CNT
257C  67        906          MOV     H,A
257D  C9        907          RET
              908  DME:
257E  2E00      909          MVI     L,0
2580  2600      910          MVI     H,0
2582  C9        911          RET
              912  DIGH:
              913  ;         MVI     L,34
              914  ;         MVI     H,0
2583  DBE4      915          IN      ALTPORT       ;ALTIMETER READING
2585  6F        916          MOV     L,A
2586  2600      917          MVI     H,0
2588  C9        918          RET
              919  DIGLI:
              920  ;         MVI     L,35
              921  ;         MVI     H,0
```

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;;8589 2A5288      922           LHLD    LIGHTS
;;858C C9          923           RET
;;                 924   DIGMOD:
;;858D DBE5        925           IN      PUSHPORT
;;858F 6F          926           MOV     L,A
;;8590 2600        927           MVI     H,0
;;                 928   ;       MVI     L,36
;;                 929   ;       MVI     H,0
;;8592 C9          930           RET
;;                 931   DIGTIM:
;;8593 2A5C88      932           LHLD    TIM
;;8596 C9          933           RET
;;                 934   STATE:
;;                 935   ;       THISMACHINE HAS TWO STATES
;;                 936   ;       STATE 0   THE MACHINE STAYS IN THIS STATE FOR 30 SECS.
;;                 937   ;                 AFTER 30 SECS. ELAPSE, IT TURNS ON THE PROPER LIGHT
;;                 938   ;                 AND SHIFTS TO STATE 1.
;;                 939   ;
;;                 940   ;       STATE 1   THE MACHINE STAYS IN STATE 1 UNTIL THE PROPER
;;                 941   ;                 PUSHBUTTON IS DEPRESSED.(LIGHT X GOES WITH PB X, ETC)
;;                 942   ;                 THE CORRESPONDING LIGHT IS TURNED OFF AND THE
;;                 943   ;                 MACHINE SHIFTS TO STATE 0.
;;8597 F5          944           PUSH    PSW
;;8598 E5          945           PUSH    H
;;8599 C5          946           PUSH    B
;;859A 3A4E88      947           LDA     ST
;;859D B7          948           ORA     A         ;SET THE FLAGS
;;859E C2C185      949           JNZ     STATE1
;;                 950   STATE0:
;;85A1 212C01      951           LXI     H,THSEDY  ;LOAD THE NUMBER OF TIMER CLICKS NEEDED FOR 30 SEC
;;85A4 AF          952           XRA     A         ;CLEAR CARRY
;;85A5 ED4B5088    953           LBCD    PTIM
;;85A9 ED42        954           DSBC    B
;;85AB C2B785      955           JNZ     BPTIM
;;85AE CDDA85      956           CALL    TONL
;;85B1 CD3D86      957           CALL    TONS      ;STATE=1
;;85B4 C3D685      958           JMP     BACK
;;                 959   BPTIM:
;;85B7 2A5088      960           LHLD    PTIM
;;85BA 23          961           INX     H
;;85BB 225088      962           SHLD    PTIM
;;85BE C3D685      963           JMP     BACK
;;                 964   STATE1:
;;85C1 CD2586      965           CALL    PB        ;RETURN PUSHBUTTON STATUS IN Z FLAG
;;85C4 C2D685      966           JNZ     BACK
;;                 967   PBON:
;;85C7 CDFB85      968           CALL    TOFFL     ;TURN OFF LITE
;;85CA CD4586      969           CALL    TOFFS     ;STATE=0
;;85CD CD1C86      970           CALL    CPTIM     ;PTIM = 0
;;85D0 CD5C86      971           CALL    SWPBLITE   ;SWITCH TO NEXT PUSHBUTON + LITE SET
;;85D3 C3D685      972           JMP     BACK
;;                 973   BACK:
;;85D6 C1          974           POP     B
;;85D7 E1          975           POP     H
;;85D8 F1          976           POP     PSW
;;85D9 C9          977           RET
;;                 978   TONL:
;;85DA F5          979           PUSH    PSW
;;85DB 3A5688      980           LDA     BINRY
;;85DE FE00        981           CPI     0
;;85E0 C2EF85      982           JNZ     ON2
;;85E3 3A5288      983           LDA     LIGHTS
;;85E6 E6FE        984           ANI     0FEH    ;
;;85E8 D3C5        985           OUT     LITEPORT     ;BIT 0  PORT B   5 VOLTS
;;85EA 325288      986           STA     LIGHTS
;;85ED F1          987           POP     PSW
```

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;;85EE C9          988          RET
;;               989  ON2:
;;85EF 3A5288      990          LDA     LIGHTS
;;85F2 E6FD        991          ANI     0FDH    ;
;;85F4 D3C5        992          OUT     LITEPORT     ;BIT 1 PORT B  5 VOLTS
;;85F6 325288      993          STA     LIGHTS
;;85F9 F1          994          POP     PSW
;;85FA C9          995          RET
;;               996  TOFFL:
;;85FB F5          997          PUSH    PSW
;;85FC 3A5688      998          LDA     BINRY
;;85FF FE00        999          CPI     0
;;8601 C21086      1000         JNZ     OFF2
;;8604 3A5288      1001         LDA     LIGHTS
;;8607 F601        1002         ORI     01H         ;
;;8609 D3C5        1003         OUT     LITEPORT     ;BIT 0 PORT B  0 VOLTS
;;860B 325288      1004         STA     LIGHTS
;;860E F1          1005         POP     PSW
;;860F C9          1006         RET
;;               1007 OFF2:
;;8610 3A5288      1008         LDA     LIGHTS      ;
;;8613 F602        1009         ORI     02H
;;8615 D3C5        1010         OUT     LITEPORT    ;BIT 0 PORT B  0 VOLTS
;;8617 325288      1011         STA     LIGHTS
;;861A F1          1012         POP     PSW
;;861B C9          1013         RET
;;               1014 CPTIM:
;;861C E5          1015         PUSH    H
;;861D 210000      1016         LXI     H,0
;;8620 225088      1017         SHLD    PTIM        ;CLEAR PTIM
;;8623 E1          1018         POP     H
;;8624 C9          1019         RET
;;               1020 PB:
;;8625 3A5686      1021         LDA     BINRY
;;8628 FE00        1022         CPI     0
;;862A C23586      1023         JNZ     PB2
;;862D DBE5        1024         IN      PUSHPORT    ;PUSHBUTOON STATUS
;;862F 325488      1025         STA     MODES
;;8632 E601        1026         ANI     01H         ;BIT 0  PORT B
;;8634 C9          1027         RET                 ;STATUS RETURNED IN Z FLAG
;;               1028 PB2:
;;8635 DBE5        1029         IN      PUSHPORT
;;8637 325488      1030         STA     MODES
;;863A E602        1031         ANI     02H         ;BIT 1  PORT B
;;863C C9          1032         RET
;;               1033 TONS:
;;863D F5          1034         PUSH    PSW
;;863E 3E01        1035         MVI     A,01H       ;
;;8640 324E88      1036         STA     ST          ;STATE=1
;;8643 F1          1037         POP     PSW
;;8644 C9          1038         RET
;;               1039 TOFFS:
;;8645 F5          1040         PUSH    PSW
;;8646 3E00        1041         MVI     A,0
;;8648 324E88      1042         STA     ST
;;864B F1          1043         POP     PSW
;;864C C9          1044         RET
;;               1045 FLIP:
;;               1046 ;                       ;TOGGLE LIGHT 3, TOGGLE LIGHT 4 TOGETHER
;;864D F5          1047         PUSH    PSW
;;864E 3A5288      1048         LDA     LIGHTS
;;8651 EE04        1049         XRI     04H     ;FLIP BIT 2
;;8653 EE08        1050         XRI     08H     ;FLIP BIT 3
;;8655 325288      1051         STA     LIGHTS
;;8658 D3C5        1052         OUT     LITEPORT
;;865A F1          1053         POP     PSW
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¿¿865B C9          1054          RET
¿¿                 1055    SWPBLITE:
¿¿                 1056    ;       IF YOU ARE USING PB0 AND LITE0,
¿¿                 1057    ;       USE PB1 AND LITE1.
¿¿                 1058    ;       IF YOU ARE USING PB1 AND LITE1,
¿¿                 1059    ;       USE PB0 AND LITE0.
¿¿                 1060    ;
¿¿865C F5          1061          PUSH    PSW
¿¿865D 3A5688      1062          LDA     BINRY
¿¿8660 EE01        1063          XRI     01H
¿¿8662 325688      1064          STA     BINRY
¿¿8665 F1          1065          POP     PSW
¿¿8666 C9          1066          RET
¿¿                 1067    CTIM:
¿¿8667 E5          1068          PUSH    H
¿¿8668 210000      1069          LXI     H,0       ;HL=0
¿¿866B 225C88      1070          SHLD    TIM       ;SECOND COUNTER = 0
¿¿866E E1          1071          POP     H
¿¿866F C9          1072          RET
¿¿                 1073    SETCDIG:
¿¿                 1074    ;
¿¿                 1075    ;                       SET DIGIT COUNTER CNTDIG
¿¿                 1076    ;
¿¿8670 F5          1077          PUSH    PSW
¿¿8671 3E00        1078          MVI     A,0
¿¿8673 324D88      1079          STA     CNTDIG    ;CNTDIG=0
¿¿8676 F1          1080          POP     PSW
¿¿8677 C9          1081          RET
¿¿                 1082    INTWODIG:
¿¿8678 E5          1083          PUSH    H
¿¿8679 C5          1084          PUSH    B
¿¿867A D5          1085          PUSH    D
¿¿                 1086                  ;CHECK TO SEE IF THERE IS
¿¿                 1087                  ;A TWO DIGIT INPUT READY
¿¿                 1088                  ;
¿¿                 1089                  ;IF THERE IS NOT,
¿¿                 1090                  ;  RETURN WITH Z SET
¿¿                 1091                  ;
¿¿                 1092                  ;IF THERE IS,
¿¿                 1093                  ;  RETURN WITH Z RESET
¿¿                 1094                  ;
¿¿                 1095                  ;
¿¿867B CDB186      1096          CALL    DI        ;GET DIGIT IF WAITING
¿¿867E CAAD86      1097          JZ      INPUTR    ; IF Z SET, NOTGHING WAITING
¿¿                 1098    ;
¿¿                 1099    ;
¿¿                 1100                  ;Z NOT SET, SO DIGIT IN ACC
¿¿8681 E60F        1101          ANI     0FH       ;CONVERT ASCII DIGIT TO BINARY DIGIT
¿¿                 1102    ;       CALL    HDMP
¿¿                 1103    ;       CALL    CRLF
¿¿8683 57          1104          MOV     D,A       ;SAVE DIGIT IN D
¿¿8684 3A4D88      1105          LDA     CNTDIG    ;CNTDIG IS DIGIT COUNTER
¿¿8687 3C          1106          INR     A
¿¿8688 324D88      1107          STA     CNTDIG
¿¿868B FE02        1108          CPI     02H       ;
¿¿868D CA9886      1109          JZ      INPUTE    ;IF Z SET, COUNT IS 2
¿¿                 1110    ;
¿¿                 1111    ;
¿¿                 1112                  ;HAVE INPUT IN D, SAVE IN B
¿¿8690 7A          1113          MOV     A,D       ;
¿¿8691 324B88      1114          STA     INPUTS    ;SAVE FIRST INPUT DIGIT
¿¿8694 AF          1115          XRA     A         ;Z IS SET
¿¿8695 C3AD86      1116          JMP     INPUTR
¿¿                 1117    INPUTE:
¿¿8698 3A4B88      1118          LDA     INPUTS    ;MOVE FIRST INPUT DIGIT IN ACC
¿¿869B 07          1119          RLC
```

```
1120            RLC
1121            RLC
1122            MOV     B,A     ;(B)=8*(INPUTS)
1123            LDA     INPUTS  ;
1124            ADD     A       ;(A)=2*(INPUTS)
1125            ADD     B       ;(A)=2*(INPUTS)+8*(INPUTS)=10*(INPUTS)
1126            ADD     D       ;ADD IN SECOND INPUT DIGIT
1127            STA     TWODIG
1128            MVI     A,0
1129            STA     CNTDIG  ;CLEAR THE COUNTER
1130    INPUTR:
1131            POP     D
1132            POP     B
1133            POP     H
1134            RET
1135    DI:
1136    ;                       ACC AND FLAGS ARE CHENGED
1137    ;                       GET INPUT IF WAITING
1138    ;                       OTHERWISE RETURN WITH Z SET
1139    ;
1140    ;                       SEE IF INPUT IS ADECIMAL DIGIT,
1141    ;                       IF NOT RETURN WITH Z SET
1142    ;
1143    ;                       IF INPUT IS A DECIMAL DIGIT,
1144    ;                       ECHO IT AND RETURN IN ACC
1145    ;
1146    ;
1147            IN      S8251
1148            ANI     RXRDY   ;IS THERE INPUT DATA YET
1149            RZ              ;IF Z IS SET, RETURN
1150    ;
1151    ;                       READ THE CHAR
1152    ;
1153            IN      D8251   ;GET CHAR
1154            ANI     07FH    ;  CHOP OFF PARITY
1155    ;
1156    ;                       TEST FOR DIGIT FROM 0 TO 9
1157    ;
1158            CPI     30H     ; COMPARE WITH ASCII 0
1159            JM      DINODIG ; JUMP IF LESS THAN
1160            CPI     3AH     ;COMPARE WITH ASCII COLON
1161            JP      DINODIG ;  JUMP IF GREATER OR EQUAL
1162            CALL    CO      ;HAVE LEGAL DIGIT IN ACC, Z IS RESET
1163            RET
1164    ;
1165    ;
1166    DINODIG:
1167            XRA     A       ;Z IS SET
1168            RET
1169    DISPLAY:
1170            PUSH    PSW
1171            PUSH    H
1172            PUSH    B
1173                            ;DISPLAY MEMORY LOCATION
1174                            ;CORRESPONDING TO TWODIG ADDRESS
1175                            ;
1176            LDA     CNT     ;INTERRUPT COUNT LOADED IN ACC
1177            CPI     9       ; IS THIS THE NINTH INTERRUPT
1178            JNZ     DISPLAYR ;  RETURN IF NOT NINE
1179                            ;
1180                            ;
1181            LDA     TWODIG  ;LOAD TWO DIGIT NUMBER
1182            CPI     0       ;  IF IT IS ZERO, NOTHING TO DISPLAY YET
1183            JZ      DISPLAYR ;   SO RETURN
1184                            ;
1185                            ;
```

```
;;86DD  87          1186            ADD     A       ;FORM BYTE OFFSET IN ACC
;;86DE  D602        1187            SUI     2       ;  VALUE OF 1 IS AN OFFSET OF ZERO
;;              1188                            ;
;;86E0  2600        1189            MVI     H,0     ;MOVE ACC OFFSET
;;86E2  6F          1190            MOV     L,A     ;  HL HAS ACC OFFSET
;;86E3  ED4B5788    1191            LBCD    SAVEDE  ;    BASE ADDRESS OF CURRENT STORAGE IN BC
;;86E7  09          1192            DAD     B       ;      ADDED TO OFFSET TO FORM POINTER TO
;;              1193                            ;        MEMORY LOCATION YOU WANT TO SEE
;;              1194                            ;
;;86E8  CD2A87      1195            CALL    CRLF
;;86EB  CDF786      1196            CALL    HDMP2   ;
;;              1197                            ;
;;              1198                            ;
;;              1199    ;       CALL    CRLF
;;              1200    ;       LDA     TWODIG
;;              1201    ;       CALL    HDMP
;;              1202    ;       CALL    CRLF
;;              1203    ;       LXI     H,SAVEDE
;;              1204    ;       CALL    HDMP2
;;              1205    ;       CALL    CRLF
;;86EE  3E00        1206            MVI     A,0     ;ZERO
;;86F0  324C88      1207            STA     TWODIG  ;  TWODIG
;;              1208                            ;
;;              1209                            ;
;;              1210    DISPLAYR:
;;86F3  C1          1211            POP     B
;;86F4  E1          1212            POP     H
;;86F5  F1          1213            POP     PSW
;;86F6  C9          1214            RET
;;              1215            ; DUMP THE CONTENTS OF MEMORY IN HEX
;;              1216            ; H HOLDS STARTING ADDRESS OF DUMP
;;              1217            ; A REG IS USED IN HDUMP
;;86F7  F5          1218    HDMP2:  PUSH    PSW
;;86F8  E5          1219            PUSH    H
;;86F9  23          1220            INX     H
;;86FA  7E          1221            MOV     A,M
;;86FB  CD0987      1222            CALL    HDMP
;;86FE  2B          1223            DCX     H
;;86FF  7E          1224            MOV     A,M
;;8700  CD0987      1225            CALL    HDMP
;;8703  CD2A87      1226            CALL    CRLF
;;8706  E1          1227            POP     H
;;8707  F1          1228            POP     PSW
;;8708  C9          1229            RET
;;              1230    ;               HDMP USES THE A REG
;;8709  F5          1231    HDMP:   PUSH    PSW     ;SAVE ACC
;;870A  F5          1232            PUSH    PSW     ;  TWICE
;;870B  E6F0        1233            ANI     0F0H    ;ISOLATE THE HIGH ORDER NYBBLE
;;870D  0F          1234            RRC
;;870E  0F          1235            RRC
;;870F  0F          1236            RRC
;;8710  0F          1237            RRC             ;HI DIG SHIFTED RIGHT BY 4
;;8711  CD2287      1238            CALL    BINHE   ;PRINT HIGH ORDER DIGIT
;;8714  CD0B88      1239            CALL    CO      ;PRINT ASCII FORM OF HIGH DIGIT
;;8717  F1          1240            POP     PSW     ;RESTORE THE ACC TO VALUE AT ENTRY
;;8718  E60F        1241            ANI     0FH     ;ISOLATE THE LOW ORDER NYBBLE
;;871A  CD2287      1242            CALL    BINHE   ;
;;871D  CD0B88      1243            CALL    CO      ;
;;8720  F1          1244            POP     PSW     ;
;;8721  C9          1245            RET
;;8722  C630        1246    BINHE:  ADI     30H     ;
;;8724  FE3A        1247            CPI     3AH     ;
;;8726  D8          1248            RC
;;8727  C607        1249            ADI     7H
;;8729  C9          1250            RET
;;              1251    ;               CRLF USES ONLY THE AREG
```

```
;;872A F5          1252  CRLF:   PUSH    PSW
;;872B 3E0D        1253          MVI     A,0DH
;;872D CD0B88      1254          CALL    CO
;;8730 3E0A        1255          MVI     A,0AH
;;8732 CD0B88      1256          CALL CO
;;8735 F1          1257          POP     PSW
;;8736 C9          1258          RET
;;                 1259  ;DATAOVRUN:
;;                 1260  ;       ARE WE FILLING FASTER THAN WE ARE EMPTYING
;;                 1261  ;       PUSH    PSW
;;                 1262  ;       PUSH    B
;;                 1263  ;       LDA     EMHICHB
;;                 1264  ;       MOV     B,A
;;                 1265  ;       LDA     FMHICHB
;;                 1266  ;       CMP     B
;;                 1267  ;       JNZ     D1
;;                 1268  ;                       DATA OVERRUN
;;                 1269  ;       MVI     A,'O'
;;                 1270  ;       CALL    BO
;;                 1271  ;       HLT
;;                 1272  ;D1:
;;                 1273  ;       POP     B
;;                 1274  ;       POP     PSW
;;                 1275  ;       RET
;;                 1276  ;VALIDMP:
;;                 1277  ;                       LET THE FILLER CATCHUP WITH EMPTYER
;;                 1278  ;       PUSH    PSW
;;                 1279  ;       PUSH    B
;;                 1280  ;       LDA     FILLONE
;;                 1281  ;       CPI     0
;;                 1282  ;       JNZ     V1
;;                 1283                          ;ONE BUFFER HAS NOT YET BEEN FILLED
;;                 1284  ;V2:    LDA     FMHICHB
;;                 1285  ;       CPI     0
;;                 1286  ;       MVI     A,'W'
;;                 1287  ;       CALL    CO
;;                 1288  ;       JZ      V2
;;                 1289                          ;ONE BUFFER HAS BEEN FILLED
;;                 1290  ;       MVI     A,1
;;                 1291  ;       STA     FILLONE
;;                 1292  ;V1:
;;                 1293                          ;MAKE SURE FILLER STAYS AHEAD OF EMPTYER
;;                 1294  ;       LDA     EMHICHB
;;                 1295  ;       MOV     B,A
;;                 1296  ;       LDA     FMHICHB
;;                 1297  ;       CMP     B
;;                 1298  ;       LDA     FMHICHB
;;                 1299  ;       ADI     30H
;;                 1300  ;       CALL    CO
;;                 1301  ;       JZ      V1
;;                 1302  ;       POP     B
;;                 1303  ;       POP     PSW
;;                 1304  ;       RET
;;                 1305  INITSEMA:
;;                 1306                          ;MARK ALL BUFFERS EMPTY
;;8737 F5          1307          PUSH    PSW
;;8738 C5          1308          PUSH    B
;;8739 E5          1309          PUSH    H
;;873A 216A88      1310          LXI     H,SEMAPHORE       ;
;;873D 060A        1311          MVI     B,10
;;873F 3645        1312  S1:     MVI     M,'E'
;;8741 23          1313          INX     H         ;ADDRESS NEXT SEMIPHORE
;;8742 05          1314          DCR     B         ;ONE LESS SEMIPHORE TO INITIALISE
;;8743 C23F87      1315          JNZ     S1        ;REPEAT UNTIL ALL SEMIPHORES ARE INITIALISED
;;8746 E1          1316          POP     H
;;8747 C1          1317          POP     B
```

```
8748  F1          1318          POP     PSW
8749  C9          1319          RET
      8           1320    TSTFULL:
      8           1321                                  ;WAIT UNTIL BUFFER EMPTY (INFINITE LOOP!)
874A  F5          1322          PUSH    PSW
874B  C5          1323          PUSH    B
874C  E5          1324          PUSH    H
874D  216A88      1325          LXI     H,SEMAPHORE
8750  3A5B88      1326          LDA     FWHICHB
8753  0600        1327          MVI     B,0
8755  4F          1328          MOV     C,A
8756  09          1329          DAD     B         ;(HL):= SEMAPHORE+(FWHICHB)
8757  7E          1330    FULL1:MOV     A,M       ;(A):= (SEMAPHORE+(FWHICHB))
8758  FE46        1331          CPI     'F'       ;SEE IF BUFFER FULL
875A  CC6187      1332          CZ      OVRUN     ;WAIT TIL EMPTY
875D  E1          1333          POP     H
875E  C1          1334          POP     B
875F  F1          1335          POP     PSW
8760  C9          1336          RET
      8           1337    OVRUN:
8761  3E4F        1338          MVI     A,'O'
8763  CD0B88      1339          CALL    CO
8766  3E56        1340          MVI     A,'V'
8768  CD0B88      1341          CALL    CO
876B  3A5B88      1342          LDA     FWHICHB
876E  C641        1343          ADI     'A'
8770  CD0B88      1344          CALL    CO
8773  C30000      1345          JMP     0
      8           1346    TSTEMPTY:
      8           1347                                  ;WAIT UNTIL BUFFER FULL
8776  F5          1348          PUSH    PSW
8777  C5          1349          PUSH    B
8778  E5          1350          PUSH    H
8779  216A88      1351          LXI     H,SEMAPHORE
877C  3A6888      1352          LDA     EMHICHB
877F  0600        1353          MVI     B,0
8781  4F          1354          MOV     C,A
8782  09          1355          DAD     B
8783  7E          1356    EMPTY1:MOV    A,M       ;(A):=(SEMAPHORE+(EMHICHB))
8784  FE45        1357          CPI     'E'       ;SEE IF BUFFER EMPTY
8786  F5          1358          PUSH    PSW       ;SAVE Z FLAG
8787  3A6888      1359          LDA     EMHICHB
878A  C630        1360          ADI     '0'       ;CONVERT TO ASCII
      8           1361    ;      CALL    CO
878C  F1          1362          POP     PSW       ;RESTORE Z FLAG
878D  CA8387      1363          JZ      EMPTY1    ;WAIT UNTIL FULL
8790  E1          1364          POP     H
8791  C1          1365          POP     B
8792  F1          1366          POP     PSW
8793  C9          1367          RET
      8           1368    SETFULL:
      8           1369                                  ;MARK BUFFER FULL
8794  F5          1370          PUSH    PSW
8795  C5          1371          PUSH    B
8796  E5          1372          PUSH    H
8797  216A88      1373          LXI     H,SEMAPHORE
879A  3A5B88      1374          LDA     FWHICHB
879D  0600        1375          MVI     B,0
879F  4F          1376          MOV     C,A       ;(BC):=(FWHICHB)
87A0  09          1377          DAD     B         ;(HL):=SEMAPHORE+(FWHICHB)
87A1  3E46        1378          MVI     A,'F'     ;MARK IT FULL
87A3  77          1379          MOV     M,A       ;(SEMAPHORE+(FWHICHB)):='F'
87A4  E1          1380          POP     H
87A5  C1          1381          POP     B
87A6  F1          1382          POP     PSW
87A7  C9          1383          RET
```

```
                1384  SETEMPTY:
                1385                          ;MARK BUFFER EMPTY
87A8  F5        1386          PUSH    PSW
87A9  C5        1387          PUSH    B
87AA  E5        1388          PUSH    H
87AB  216A88    1389          LXI     H,SEMAPHORE
87AE  3A6888    1390          LDA     EWHICHB
87B1  0600      1391          MVI     B,0
87B3  4F        1392          MOV     C,A             ;(BC):=(EWHICHB)
87B4  09        1393          DAD     B       ;(HL):=SEMAPHORE+(EWHICHB)
87B5  3E45      1394          MVI     A,'E'   ;MARK IT EMPTY
87B7  77        1395          MOV     M,A     ;(SEMAPHORE+(EWHICHB)):='E'
87B8  E1        1396          POP     H
87B9  C1        1397          POP     B
87BA  F1        1398          POP     PSW
87BB  C9        1399          RET
                1400  INITRE:
87BC  CD7086    1401          CALL    SETCDIG ;ZERO DIGIT COUNTER, CNTDIG
87BF  CD2783    1402          CALL    CNTR0
87C2  CD1683    1403          CALL    CNTR1
87C5  3E0A      1404          MVI     A,10
87C7  326188    1405          STA     FLAG
87CA  3E80      1406          MVI     A,80H     ;FORMAT 8255 AS MODE 0,
87CC  D3EB      1407          OUT     0EBH      ;  ALL THREE PORTS OUTPUT ON J-2 8004
87CE  110090    1408          LXI     D,BUFF0   ;  SAVEDE POINTER =
87D1  ED535788  1409          SDED    SAVEDE    ;  SET TO BASE ADDRESS OF ALL TEN BUFFERS
87D5  3E00      1410          MVI     A,00H     ; POINTER THAT TELLS WHICH BUFFER
87D7  325B88    1411          STA     FWHICHB   ;  IS BEING FILLED = 0
87DA  210008    1412          LXI     H,2048  ;COUNTER TO TELL HOW MUCH
87DD  225988    1413          SHLD    REMAIN  ;  OF A BUFFER IS UNFILLED.
87E0  110090    1414          LXI     D,BUFF0   ; POINTER TO BASE ADDRESS OF CURRENT
87E3  210000    1415          LXI     H,0     ;ZERO OUT
87E6  225E88    1416          SHLD      CNT     ;  INTERRUPT COUNTER
87E9  ED537688  1417          SDED    CURRBUF   ;  BUFFER BEING FILLED
                1418  ;         MVI     A,0       ;
                1419  ;         STA     FILLONE   ;FILLONE=0, MEANS ALL BUFFERS ARE EMPTY
                1420                            ; OF DATA.
87ED  3E80      1421          MVI     A,080H
87EF  D3C7      1422          OUT     LITECTRL  ;FORMAT LIGHTS
87F1  3E9B      1423          MVI     A,09BH
87F3  D3E7      1424          OUT     J18004    ;FORMAT PUSHBUTTONS.
87F5  3EFF      1425          MVI     A,0FFH    ;TURN OFF LIGHTS
87F7  D3C5      1426          OUT     LITEPORT
87F9  325288    1427          STA     LIGHTS    ;  SAVE LIGHT STATUS
87FC  CD4586    1428          CALL    TOFFS   ;STATE=0
87FF  CD1C86    1429          CALL    CPTIM     ;PTIM=0
8802  CD6786    1430          CALL    CTIM      ;CLEAR SECOND COUNTER
8805  3E00      1431          MVI     A,0
8807  325688    1432          STA     BINRY     ;BINRY=0, PB0 AND LITE0 FIRST
880A  C9        1433          RET
                1434  ;*************************************************
                1435  ;               CHARACTER OUTPUT ROUTINE
                1436  ; CO OUTPUTS ONE CHARACTER FROM ACC TO TERMINAL
                1437  ; VIA THE USART. ALL REGISTERS AND FLAGS ARE
                1438  ; PRESERVED. THE CHARACTER  IT OUTPUTS IS IN THE ACC.
                1439  ;*************************************************
880B  F5        1440  CO:     PUSH    PSW
880C  C5        1441          PUSH    B
880D  4F        1442          MOV     C,A     ;SAVE A REG
880E  00        1443  CO0:    NOP             ;DELAY
880F  00        1444          NOP             ;
8810  DBD9      1445          IN      S0251   ;GET USART STATUS
8812  E601      1446          ANI     TXRDY   ;CHECK TRANSMIT READY FLAG
8814  CA0E88    1447          JZ      CO0     ;NOT READY
8817  00        1448          NOP
              1449          MOV
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;;8819 00          1450          NOP
;;881A 00          1451          NOP
;;881B 79          1452          MOV     A,C       ;READY TO TRANSMIT , RESTORE CHAR TO A REG
;;881C D3CC        1453          OUT     D8251     ;SEND IT
;;881E C1          1454          POP     B
;;881F F1          1455          POP     PSW
;;8820 C9          1456          RET
;;                 1457  INITUSART:
;;8821 CD2B88      1458          CALL    RUSART    ;MASTER RESET SEQUENCE
;;8824 CD3C88      1459          CALL    MUSART    ;SET MODE IN USART
;;8827 CD4388      1460          CALL    CUSART    ;SET COMMAND IN USART
;;882A C9          1461          RET
;;882B 3E80        1462  RUSART: MVI     A,80H     ;RESET 8251
;;882D D3CD        1463          OUT     C8251     ;
;;882F E3          1464          XTHL
;;8830 E3          1465          XTHL
;;8831 D3CD        1466          OUT     C8251
;;8833 E3          1467          XTHL
;;8834 E3          1468          XTHL
;;8835 3E40        1469          MVI     A,40H     ;
;;8837 D3CD        1470          OUT     C8251     ;
;;8839 E3          1471          XTHL
;;883A E3          1472          XTHL
;;883B C9          1473          RET
;;883C 3E4E        1474  MUSART: MVI     A,USMODE
;;883E D3CD        1475          OUT     C8251
;;8840 E3          1476          XTHL
;;8841 E3          1477          XTHL
;;8842 C9          1478          RET
;;8843 3E37        1479  CUSART: MVI     A,USCMD   ;REST ERROR FLAGS
;;                 1480                            ;   ENABLE TRANSMIT
;;                 1481                            ;      ENABLE RECIEVE
;;                 1482                            ;         READY DATA SET
;;                 1483                            ;
;;                 1484                            ;
;;8845 D3CD        1485          OUT C8251 ;GIVE COMMAND
;;8847 E3          1486          XTHL
;;8848 E3          1487          XTHL
;;8849 C9          1488          RET
;;884A C9          1489          RET
;;                 1490                            ;
;;004C             1491  BYTPERSEC  EQU   2*38     ; HOW MANY BYTES PER SEC OF DATA
;;012C             1492  THSEBY:  EQU     300       ;NUMBER OF TIMER CLICKS NEEDED FOR 30 DELAY
;;                 1493                            ;300 FOR .1 SEC TIMER CLICKS
;;                 1494                            ;150 FOR .2 SEC TIMER CLICKS
;;0010             1495  TLOW     EQU     010H      ;
;;0027             1496  THIGH    EQU     027H      ;2710H=10000D
;;                 1497  ;TLOW    EQU     020H      ;
;;                 1498  ;THIGH   EQU     04EH      ;4E20H=20000D
;;004E             1499  USMODE:  EQU     04EH      ;
;;0037             1500  USCMD:   EQU     037H      ;
;;884B 00          1501  INPUTS:  DB      0
;;884C 00          1502  TWODIG:  DB      0
;;884D 00          1503  CNTDIG:  DB      0
;;00CD             1504  S8251    EQU     0CDH
;;00CD             1505  C8251    EQU     S8251
;;00CC             1506  D8251    EQU     0CCH
;;0002             1507  RXRDY    EQU     02H
;;0001             1508  TXRDY    EQU     01H
;;884E 0000        1509  ST:      DW      0
;;8850 0000        1510  PTIM:    DW      0
;;8852 0000        1511  LIGHTS:  DW      0
;;8854 0000        1512  MODES:   DW      0
;;8856 00          1513  BINRY:   DB      0
;;8857 0090        1514  SAVEDE:  DW      BUFF0
;;8859 0008        1515  REMAIN:  DW      2048
```

```
885B  00          1516  FWHICHB: DB    0        ;FILL WHICH BUFFER
885C  0000        1517  TIM:     DW    0
885E  0000        1518  CNT:     DW    0
8860  00          1519  FILLONE: DB    0
8861  00          1520  FLAG:    DB    0
8862  0000        1521  SAVE:    DW    0
8864  0000        1522  SAV:     DW    0
8866  0000        1523  EREMAIN: DW    0
8868  00          1524  EWHICHB: DB    0        ;EMPTY WHICH BUFFER
8869  00          1525  TSW:     DB    0
886A  4545454545  1526  SEMAPHORE:     DB       'EEEEEEEEEE'        ;TEN BUFFER SEMIPHORES ALL 'E'
      4545454545
8874  0000        1527  ECURRBUF: DW   0
8876  0090        1528  CURRBUF: DW    BUFF0
8878  0000        1529   TEMPDE: DW    0
              1530  AVG:
887A  F5          1531        PUSH    PSW
887B  E5          1532        PUSH    H
887C  C5          1533        PUSH    B
887D  D5          1534        PUSH    D
887E  DDE5        1535        PUSHX
8880  FDE5        1536        PUSHY
8882  3A5E88      1537        LDA     CNT      ;
8885  FE00        1538        CPI     0
8887  C29688      1539        JNZ     AVG1
              1540  ;         MVI     A,'1'
              1541  ;         CALL    CO
888A  CD8388      1542        CALL    PART1
888D  FDE1        1543        POPY
888F  DDE1        1544        POPX
8891  D1          1545        POP     D
8892  C1          1546        POP     B
8893  E1          1547        POP     H
8894  F1          1548        POP     PSW
8895  C9          1549        RET
8896  FE09        1550  AVG1:    CPI     9
8898  C2A788      1551        JNZ     AVG2
889B  CDFA88      1552        CALL    PART3
889E  FDE1        1553        POPY
88A0  DDE1        1554        POPX
88A2  D1          1555        POP     D
88A3  C1          1556        POP     B
88A4  E1          1557        POP     H
88A5  F1          1558        POP     PSW
88A6  C9          1559        RET
88A7  CDBC88      1560  AVG2:    CALL    PART2
88AA  FDE1        1561        POPY
88AC  DDE1        1562        POPX
88AE  D1          1563        POP     D
88AF  C1          1564        POP     B
88B0  E1          1565        POP     H
88B1  F1          1566        POP     PSW
88B2  C9          1567        RET
              1568  PART1
88B3  21A68A      1569        LXI     H,A32
88B6  013000      1570        LXI     B,48
88B9  CDF489      1571        CALL    CLEAR
              1572  PART2:
              1573  ;         MVI     A,'2'
              1574  ;         CALL    CO
              1575  ;         CALL    CRLF
88BC  AF          1576        XRA     A
88BD  32888A      1577        STA     ITER
              1578  TP1:
              1579  ;         CALL    PORTAOFF
88C0  DD215788    1580        LXIX    PNTA16
```

```
1188C4 FD21888A  1581          LXIY    ITER
1188C8 CDBF89    1582          CALL    LD2BCDE   ;(BCDE):=A16(ITER)
1188CB           1583  ;       CALL    WBCDE     ;DUMP BCDE REGISTERS
1188CB           1584
1188CB CD4D89    1585          CALL    DSTACK    ;PUT(BCDE) ONTO 32 BIT STACK
1188CE DD21A68A  1586          LXIX    A32
1188D2 FD21888A  1587          LXIY    ITER
1188D6 CD8B89    1588          CALL    LD4BCDE   ;(BCDE):=A32(ITER)
1188D9           1589  ;       CALL    WBCDE     ;DUMP BCDE REGISTERS
1188D9 CD4D89    1590          CALL    DSTACK
1188DC CD7189    1591          CALL    FIXADD
1188DF CD5F89    1592          CALL    UDSTACK   ;(BCDE):=RESULT OF 32BIT INTEGER ADD
1188E2           1593  ;       CALL    WBCDE     ;DUMP BCDE REGISTERS
1188E2 DD21A68A  1594          LXIX    A32
1188E6 FD21888A  1595          LXIY    ITER
1188EA CDA389    1596          CALL    ST4BCDE   ;(A32(ITER)):=(BCDE)
1188ED           1597  ;       LDA     ITER
1188ED           1598  ;       CALL    HDMP
1188ED           1599  ;       CALL    CRLF
1188ED 3A888A    1600          LDA     ITER      ;CHECK MITERATION COUNT
1188F0 3C        1601          INR     A
1188F1 32888A    1602          STA     ITER
1188F4 FE0C      1603          CPI     12
1188F6 C2C088    1604          JNZ     TP1
1188F9           1605  ;       CALL    PORTAON
1188F9 C9        1606          RET
1188FA           1607  PART3:
1188FA AF        1608          XRA     A
1188FB 32888A    1609          STA     ITER
1188FE           1610  TP2:
1188FE DD215788  1611          LXIX    PNTA16
118902 FD21888A  1612          LXIY    ITER
118906 CDBF89    1613          CALL    LD2BCDE   ;(BCDE):=(A16(ITER))
118909 CD4D89    1614          CALL    DSTACK    ;(BCDE) ONTO 32 BIT STACK OF T9511
11890C DD21A68A  1615          LXIX    A32
118910 FD21888A  1616          LXIY    ITER
118914 CD8B89    1617          CALL    LD4BCDE   ;(BCDE):=(A32(ITER))
118917 CD4D89    1618          CALL    DSTACK    ;(BCDE) ONTO 32 BIT STACK OF T9511
11891A CD7189    1619          CALL    FIXADD    ;ADD 32 BIT INTEGERS TOGETHER
11891D 110A00    1620          LXI     D,10
118920 010000    1621          LXI     B,0
118923 CD4D89    1622          CALL    DSTACK
118926 CD7E89    1623          CALL    FIXDIV    ;DIVIDE BY TEN
118929 CD5F89    1624          CALL    UDSTACK   ;(BCDE) HAS AVERAGE OF TEN VALUES
11892C DD215788  1625          LXIX    PNTA16
118930 FD21888A  1626          LXIY    ITER
118934 CDD989    1627          CALL    ST2BCDE   ;(BCDE):=(A16(ITER))
118937 3A888A    1628          LDA     ITER      ;CHECK ITERATION COUNT
11893A 3C        1629          INR     A         ;
11893B 32888A    1630          STA     ITER
11893E FE0C      1631          CPI     12
118940 C2FE88    1632          JNZ     TP2
118943 C9        1633          RET
118944           1634  T95BUSY:
118944 F5        1635            PUSH    PSW
118945 DB05      1636  T95BUSY1:   IN      T9511CTRLPORT     ;INPUT THE STATUS WORD
118947 B7        1637              ORA     A                 ;SET UP FLAGS
118948 FA4589    1638              JM      T95BUSY1          ;BIT 7 SET MEANS T9511 IS BUSY
11894B F1        1639              POP     PSW               ;
11894C C9        1640            RET
11894D           1641  DSTACK:
11894D F5        1642              PUSH    PSW
11894E CD4489    1643              CALL    T95BUSY           ;WAIT UNTIL T9511 NOT BUSY
118951 7B        1644              MOV     A,E               ;LSB TO STACK
118952 D3D4      1645              OUT     T9511DATAPORT
118954 7A        1646              MOV     A,D               ;NEXT BYTE TO STACK
```

```
8955 D3D4      1647              OUT       T9511DATAPORT
8957 79        1648              MOV       A,C             ;NEXT SIG BYTE TO STACK OF T9511
8958 D3D4      1649              OUT       T9511DATAPORT
895A 78        1650              MOV       A,B             ;MSB BYTE TO STACK OF T9511
895B D3D4      1651              OUT       T9511DATAPORT
895D F1        1652              POP       PSW
895E C9        1653              RET
               1654  UDSTACK:
895F F5        1655              PUSH      PSW
8960 CD4489    1656              CALL      T95BUSY           ;WAIT UNTIL T9511 NOT BUSY
8963 DBD4      1657              IN        T9511DATAPORT     ;MSB FROM STACK OF T9511
8965 47        1658              MOV       B,A
8966 DBD4      1659              IN        T9511DATAPORT     ;NEXT BYTE FROM STACK OF T9511
8968 4F        1660              MOV       C,A
8969 DBD4      1661              IN        T9511DATAPORT     ;NEXT BYTE FROM STACK OF T9511
896B 57        1662              MOV       D,A
896C DBD4      1663              IN        T9511DATAPORT
896E 5F        1664              MOV       E,A
896F F1        1665              POP       PSW
8970 C9        1666              RET
               1667  FIXADD:
8971 F5        1668              PUSH      PSW
8972 CD4489    1669        CALL    T95BUSY
8975 3E2C      1670              MVI       A,02CH      ;32 BIT FIX POINT ADD
8977 D3D5      1671              OUT       0D5H        ;
8979 CDFC89    1672              CALL      STAT
897C F1        1673              POP       PSW
897D C9        1674              RET
               1675  FIXDIV:
897E F5        1676              PUSH      PSW
897F CD4489    1677         CALL    T95BUSY
8982 3E2F      1678              MVI       A,02FH      ;32 BIT FIX POINT DIVIDE
8984 D3D5      1679              OUT       0D5H         ;
8986 CDFC89    1680              CALL      STAT
8989 F1        1681              POP       PSW
898A C9        1682              RET
               1683  LD4BCDE:
               1684  ;
               1685  ;THIS SUBROUTINE LOADS A 32 BIT ARRAY ELEMENT INTO
               1686  ;THE REGISTERS BCDE. REGISTER B HAS MOST SIGNIFICANT BYTE,
               1687  ;REGISTER E HAS THE LEAST SIGNIFICANT BYTE.
               1688  ;
               1689  ;THIS SUBROUTINE HAS A CALLING SEQUENCE
               1690  ;       LXIX    A32
               1691  ;       LXIY    ITER
               1692  ;       CALL    LD4BCDE
898B F5        1693          PUSH        PSW
898C E5        1694          PUSH    H
               1695
898D FD6E00    1696          MOVRY   L,0
8990 FD6601    1697          MOVRY   H,1       ;(HL):=CONTENTS(ITER)
               1698
8993 29        1699          DAD     H
8994 29        1700          DAD     H         ;(HL):=4*CONTENTS(ITER)
               1701
8995 DDE5      1702          PUSHX
8997 C1        1703          POP     B         ;(BC):=(IX)
               1704
8998 09        1705          DAD     B         ;(HL):=A32(ITER)
               1706
               1707
8999 5E        1708             MOV    E,M
899A 23        1709             INX    H
899B 56        1710             MOV    D,M
899C 23        1711             INX    H
899D 4E        1712             MOV    C,M
```

```
ii899E  23          1713            INX     H
ii899F  46          1714            MOV     B,M       ;(BCDE):=(4 BYTES OF A32(I))
ii      ..          1715
ii89A0  E1          1716            POP     H
ii89A1  F1          1717            POP     PSW
ii89A2  C9          1718            RET
ii      ..          1719    ST4BCDE:
ii      ..          1720    ;
ii      ..          1721    ;THIS SUBROUTINE STORES THE REGISTERS BCDE INTO A  32 BIT ARRAY ELEMENT
ii      ..          1722    ; REGISTER B HAS MOST SIGNIFICANT BYTE,
ii      ..          1723    ;REGISTER E HAS THE LEAST SIGNIFICANT BYTE.
ii      ..          1724    ;
ii      ..          1725    ;THIS SUBROUTINE HAS A CALLING SEQUENCE
ii      ..          1726    ;       LXIX    A32
ii      ..          1727    ;       LXIY    ITER
ii      ..          1728    ;       CALL    ST4BCDE
ii89A3  F5          1729              PUSH        PSW
ii89A4  E5          1730              PUSH    H
ii89A5  C5          1731            PUSH    B
ii89A6  D5          1732            PUSH    D
ii      ..          1733
ii89A7  FD6E00      1734            MOVRY   L,0
ii89AA  FD6601      1735            MOVRY   H,1       ;(HL):=CONTENTS(ITER)
ii      ..          1736
ii89AD  29          1737            DAD     H
ii89AE  29          1738            DAD     H         ;(HL):=4*CONTENTS(ITER)
ii      ..          1739
ii89AF  DDE5        1740            PUSHX
ii89B1  C1          1741            POP     B         ;(BC):=(IX)
ii      ..          1742
ii89B2  09          1743            DAD     B         ;(HL):=A32(ITER)
ii      ..          1744
ii89B3  D1          1745            POP     D
ii89B4  73          1746            MOV     M,E
ii89B5  23          1747            INX     H
ii89B6  72          1748            MOV     M,D
ii89B7  23          1749            INX     H
ii      ..          1750
ii89B8  C1          1751            POP     B
ii89B9  71          1752            MOV     M,C
ii89BA  23          1753            INX     H
ii89BB  70          1754            MOV     M,B
ii      ..          1755
ii89BC  E1          1756            POP     H
ii89BD  F1          1757            POP     PSW
ii89BE  C9          1758            RET
ii      ..          1759
ii      ..          1760    LD2BCDE:
ii      ..          1761    ;
ii      ..          1762    ;THIS SUBROUTINE LOADS A 16 BIT ARRAY ELEMENT INTO THE REGISTERS BCDE.
ii      ..          1763    ;REGISTER BC HAS 16 BIT ZERO
ii      ..          1764    ;REGISTER DE HAS THE 16 BIT INTEGER.
ii      ..          1765    ;
ii      ..          1766    ;THIS SUBROUTINE HAS A CALLING SEQUENCE
ii      ..          1767    ;       LXIX    PNTA16
ii      ..          1768    ;       LXIY    ITER
ii      ..          1769    ;       CALL    LD2BCDE
ii89BF  F5          1770              PUSH        PSW
ii89C0  E5          1771            PUSH    H
ii      ..          1772
ii89C1  DD6E00      1773            MOVRX   L,0
ii89C4  DD6601      1774            MOVRX   H,1       ;(HL):=ADDR(A16)
ii      ..          1775
ii89C7  EB          1776            XCHG    ;(DE):=ADDR(A16)
ii      ..          1777
ii89C8  FD6E00      1778            MOVRY   L,0
```

```
;;89CB FD6601      1779          MOVRY   H,1       ;(HL):CONTENTS(ITER)
;;                1780
;;89CE 29          1781          DAD     H         ;(HL):=2*CONTENTS(ITER)
;;                1782
;;89CF 19          1783          DAD     D         ;(HL):=ADDR(A16)+2*CONTENTS(ITER)
;;                1784
;;                1785
;;89D0 5E          1786              MOV     E,M
;;89D1 23          1787              INX     H
;;89D2 56          1788              MOV     D,M     ;(DE) LOADED WITH 16 BIT INTEGER
;;                1789                              ;WHOSE ADDRESS IS IN (HL)
;;                1790
;;89D3 010000      1791          LXI     B,0       ;(BC) SET TO 0
;;                1792
;;89D6 E1          1793              POP     H
;;89D7 F1          1794              POP     PSW
;;89D8 C9          1795              RET
;;                1796  ST2BCDE:
;;                1797  ;
;;                1798  ;THIS SUBROUTINE LOADS THE REGISTERS BCDE INTO A 16 BIT ARRAY ELEMENT.
;;                1799  ;REGISTER BC HAS 16 BIT ZERO
;;                1800  ;REGISTER DE HAS THE 16 BIT INTEGER.
;;                1801  ;
;;                1802  ;THIS SUBROUTINE HAS A CALLING SEQUENCE
;;                1803  ;       LXIX    PNTA16
;;                1804  ;       LXIY    ITER
;;                1805  ;       CALL    LD2BCDE
;;89D9 F5          1806            PUSH        PSW
;;89DA E5          1807            PUSH    H
;;89DB C5          1808          PUSH    B
;;89DC D5          1809          PUSH    D
;;                1810  ;
;;                1811
;;89DD DD6E00      1812          MOVRX   L,0
;;89E0 DD6601      1813          MOVRX   H,1       ;(HL):=ADDR(A16)
;;                1814
;;89E3 EB          1815          XCHG              ;(DE):=ADDR(A16)
;;                1816
;;89E4 FD6E00      1817          MOVRY   L,0
;;89E7 FD6601      1818          MOVRY   H,1       ;(HL):=CONTENTS(ITER)
;;                1819
;;89EA 29          1820          DAD     H         ;(HL):=2*CONTENTS(ITER)
;;                1821
;;89EB 19          1822          DAD     D         ;(HL):=2*CONTENTS(ITER)+ADDR(A16)
;;                1823
;;89EC D1          1824          POP     D         ;RESTORE DE PAIR AS IT WAS ON ENTERING
;;                1825
;;                1826
;;89ED 73          1827              MOV     M,E   ;
;;89EE 23          1828              INX     H
;;89EF 72          1829              MOV     M,D       ;(DE) STORED AT ADDRESS CONTAINED IN (HL)
;;                1830
;;89F0 C1          1831          POP     B         ;RESTORE BC
;;89F1 E1          1832              POP     H
;;89F2 F1          1833              POP     PSW
;;89F3 C9          1834              RET
;;                1835  CLEAR:
;;                1836  ;
;;                1837  ;THIS SUBROUTINE HAS A CALLING SEQUENCE
;;                1838  ;       LXI     H,A32
;;                1839  ;       LXI     B,48
;;                1840  ;         CALL      CLEAR
;;                1841  ;
;;                1842  ;THIS SUBROUTINE CLEARS AN ARRAY OF 32 BIT ELEMENTS.
;;                1843  ;HL   IS THE BASE ADDRESS
;;                1844  ;BC   IS HOW MANY BYTES TO ZERO
```

```
                1845  ;
                1846
89F4  54        1847        MOV     D,H
89F5  5D        1848        MOV     E,L
89F6  13        1849        INX     D           ;(DE):=(HL)+1
                1850
89F7  3600      1851        MVI     M,00H       ;ZERO INITIAL LOCATION
89F9  EDB0      1852        LDIR                ;NOW ZERO ALL 48 BYTES
                1853
89FB  C9        1854          RET
                1855  STAT:
89FC  F5        1856          PUSH    PSW
89FD  E5        1857          PUSH    H
89FE  DBD5      1858  STAT2:  IN      0D5H
8A00  B7        1859        ORA     A
8A01  FAFE89    1860          JM      STAT2
8A04  E61E      1861          ANI     01EH        ;ISOLATE BIT 4,3,2,1
8A06  CA0E8A    1862          JZ      STAT1
8A09  3E54      1863        MVI     A,'T'
8A0B  CD0B88    1864        CALL    CO
                1865  STAT1:
8A0E  E1        1866          POP     H
8A0F  F1        1867          POP     PSW
8A10  C9        1868          RET
                1869  ALIGN:
8A11  F5        1870          PUSH    PSW
8A12  3E01      1871          MVI     A,01H
8A14  D3D4      1872          OUT     0D4H
8A16  3E00      1873          MVI     A,00H
8A18  D3D4      1874          OUT     0D4H
8A1A  3E1D      1875          MVI     A,01DH
8A1C  D3D5      1876          OUT     0D5H
8A1E  CD4489    1877          CALL    T95BUSY
                1878  HH:
8A21  DBD4      1879          IN      0D4H
8A23  FE01      1880          CPI     01H
8A25  CA218A    1881          JZ      HH
8A28  F1        1882          POP     PSW
8A29  C9        1883          RET
                1884  OK:
                1885  ;       WRITE MESSAGE OK
8A2A  D5        1886        PUSH    D
8A2B  11F68A    1887        LXI     D,OKAY
8A2E  CD4A8A    1888        CALL    MSG
8A31  CD2A87    1889        CALL    CRLF
8A34  D1        1890        POP     D
8A35  C9        1891        RET
                1892  DONE:
                1893  ;       WRITE MESSAGE DONE
8A36  D5        1894        PUSH    D
8A37  11FB8A    1895        LXI     D,DONEE
8A3A  CD4A8A    1896        CALL    MSG
8A3D  D1        1897        POP     D
8A3E  C9        1898        RET
8A3F  3E4F      1899          MVI     A,'O'
8A41  CD0B88    1900          CALL    CO
8A44  3E4B      1901          MVI     A,'K'
8A46  CD0B88    1902          CALL    CO
8A49  C9        1903          RET
                1904  ;*************************************************
                1905                              ;
                1906  ;
                1907  ;                           PRINT AMESSAGE ON CONSOLE.
                1908  ;                           D-REGISTER POINTS TO BYTE CONTAINING LENGTH
                1909  ;                           OF MESSAGE. MESSAGE IS IN THE BYTESFOLLOWING
                1910  ;                           LENGTH BYTE.
```

```
                        1911    ;
                        1912    ;
                        1913    ;                       CALLING SEQUENCE
                        1914    ;
                        1915    ;                       LXI     D,DONE
                        1916    ;                       CALL    MSG
                        1917    ;               DONE:   DB      LGTH,'DONE'
                        1918    ;               LGTH    EQU     $-(DONE+1)
                        1919    ;
                        1920    ;
                        1921    ;
                        1922    ;***************************************************************
1A4A  F5                1923    MSG:    PUSH    PSW     ;SAVE STATUS AND A REG
1A4B  E5                1924            PUSH H
1A4C  D5                1925            PUSH D
1A4D  1A                1926            LDAX    D       ;GET LENGTH OF MESSAGE
1A4E  67                1927            MOV     H,A     ;SAVE IT IN H
1A4F  13                1928            INX     D       ;POINT TO FIRST BYTE OF MESSAGE
                        1929                            ;   TO OUTPUT
1A50  1A                1930    MSG0:   LDAX    D       ;BYTE OF MESSAGE INTO A
1A51  CD0B88            1931            CALL    CO      ;  OUTPUT CHAR
1A54  13                1932            INX     D       ;POINT TO NEXT BYTE
1A55  25                1933            DCR     H       ;   NUMBER OF CHARS TO BE OUTPUT
                        1934                             ;      DIMINISHED BY ONE
1A56  C2508A            1935            JNZ     MSG0    ;BRANCH IF THERE ARE
1A59  D1                1936            POP     D
1A5A  E1                1937            POP     H
1A5B  F1                1938            POP     PSW
1A5C  C9                1939            RET
                        1940    WBCDE:
1A5D  F5                1941            PUSH    PSW
1A5E  78                1942            MOV     A,B
1A5F  CD0987            1943            CALL    HDMP
1A62  79                1944            MOV     A,C
1A63  CD0987            1945            CALL    HDMP
1A66  7A                1946            MOV     A,D
1A67  CD0987            1947            CALL    HDMP
1A6A  7B                1948            MOV     A,E
1A6B  CD0987            1949            CALL    HDMP
1A6E  CD2A87            1950            CALL    CRLF
1A71  F1                1951            POP     PSW
1A72  C9                1952            RET
                        1953    INITPORTA:
1A73  F5                1954            PUSH    PSW
1A74  3E80              1955            MVI     A,080H
1A76  D3EB              1956            OUT     0EBH
1A78  F1                1957            POP     PSW
1A79  C9                1958            RET
                        1959    PORTAON:
1A7A  F5                1960            PUSH    PSW
1A7B  3E00              1961            MVI     A,00H
1A7D  D3E8              1962            OUT     0E8H
1A7F  F1                1963            POP     PSW
1A80  C9                1964            RET
                        1965    PORTAOFF:
1A81  F5                1966            PUSH    PSW
1A82  3EFF              1967            MVI     A,0FFH
1A84  D3E8              1968            OUT     0E8H
1A86  F1                1969            POP     PSW
1A87  C9                1970            RET
1A88  0000              1971    ITER:       DW      0
1A8A  0000              1972    I:          DW      0
1A8C  A68A              1973    PNTA32:     DW      A32
1A8E                    1974    PNTA16:     EQU     SAVEDE
1A8E  0100              1975    A16:        DW      01H,02H,03H,04H,05H,06H,07H,08H,09H,0AH,0BH,0CH
1A90  0200
```

```
¿¿8A92  0300
¿¿8A94  0400
¿¿8A96  0500
¿¿8A98  0600
¿¿8A9A  0700
¿¿8A9C  0800
¿¿8A9E  0900
¿¿8AA0  0A00
¿¿8AA2  0B00
¿¿8AA4  0C00
¿¿8AA6                  1976    A32:        DS      4*20
¿¿0005                  1977    T9511CTRLPORT EQU   005H
¿¿00D4                  1978    T9511DATAPORT EQU   0D4H
¿¿8AF6  04              1979    OKAY:   DB      4,'OK',CR,LF
¿¿8AF7  4F4B
¿¿8AF9  0D
¿¿8AFA  0A
¿¿8AFB  06              1980    DONEE:  DB      6,'DONE',CR,LF
¿¿8AFC  444F4E45
¿¿8B00  0D
¿¿8B01  0A
¿¿9000                  1981            ORG     9000H
¿¿9000                  1982    BUFF0:  DS      2048*10
¿¿                      1983            END
¿¿      0 ERRORS
¿
¿R; T=0.53/3.15 09:23:38
¿
```

```
FILE: GTRAJ1   FORTRAN   A1   PRINCETON UNIVERSITY TIME-SHARING SYSTEM

      COMMON/COM/C(2000)                                                    GT
      COMMON/DEGREE/DUMMY2(5)                                               GT
      COMMON/RK/DUMMY4(112)                                                 GT
      COMMON/RUNOUT/DUMMY8(1)                                               GT
C                                                                           GT
  235 CONTINUE                                                              GT
      CALL MYINIT                                                           GT
      CALL MYRUN                                                            GT
      GOTO 235                                                              GT
      END                                                                   GT
      SUBROUTINE MYINIT                                                     GT
      CALL INPT                                                             GT
      CALL INIT                                                             GT
      CALL DYNAMI                                                           GT
      RETURN                                                                GT
      END                                                                   GT
      SUBROUTINE MYRUN                                                      GT
      COMMON/COM/C(2000)                                                    GT
      COMMON/RUNCUT/DAN                                                     GT
      COMMON/STNAV/XST(7),YST(7),ZST(7),DIREQ(7),ISTDME,ISTVOR              GT
     1,R1(40),NOYES(40),SIGMA(40)                                           GT
      COMMON/DOUBLE/DSEED,DDS                                               GT
      DOUBLE PRECISION DSEED,DDS                                            GT
      EQUIVALENCE (C(203),TIME),(C(207),NSTEP)                              GT
      EQUIVALENCE (C(211),TIMPR),(C(212),TIMPLT),(C(213),TIMTTY)            GT
      EQUIVALENCE (C(241),J1),(C(244),TIMSOF)                               GT
C                                                                           GT
C***************TEMPORARILY:                                               GT
      DO 259 I=1,40                                                         GT
  259 R1(I)=0.                                                              GT
C                                                                           GT
      DAN=0.                                                                GT
C                                                                           GT
      CALL ERROR                                                            GT
C                                                                           GT
  242 CONTINUE                                                              GT
      IF(TIME.LT.TIMSOF)GOTO 82                                             GT
      DAN=2.                                                                GT
      CALL OUTPT                                                            GT
      CALL FINT                                                             GT
      GOTO 100                                                              GT
C                                                                           GT
   82 CONTINUE                                                              GT
C                                                                           GT
C***NOISE HAS TO BE DRAWN FROM RANDOM GEN FOR EACH CHANN EVERY DT AND       GT
C***BE AVAILABLE FOR SUBROUTINE OUTPT AT WHATEVER REQUIRED RECORDING        GT
C***INSTANTS.                                                               GT
C*****CALL GGNPM(DSEED,30,R1)                                               GT
      DSEED=DSEED+DDS                                                       GT
C                                                                           GT
      CALL LOGIC                                                            GT
C***R.K. LOOP                                                               GT
C                                                                           GT
      DO 246 J=1,4                                                          GT
      J1=J                                                                  GT
```

```
      CALL ROTAT                                                        GTR
      CALL DYNAM                                                        GTR
C                                                                       GTR
      IF(TIME.LE.0.)CALL OUTPT                                          GTR
      CALL RKG                                                          GTR
  246 CONTINUE                                                          GTR
C                                                                       GTR
C                                                                       GTR
      NSTEP=NSTEP+1                                                     GTR
      IF(TIME.LE.TIMPR.AND.TIME.LE.TIMPLT.AND.TIME.LE.TIMTTY)GOTO 242   GTR
      CALL OUTPT                                                        GTR
      GOTO 242                                                          GTR
  100 CONTINUE                                                          GTR
      RETURN                                                            GTR
      END                                                               GTR
      BLOCK       DATA                                                  GTR
      COMMON/DEGREE/TET0,Q0(50),PSI0J,PHI0J,WP0J(50),WR0J(50)           GTR
      COMMON/PROG/TACCX(50),TACCY(50),TACCZ(50),TPROG(50),              GTR
     1WPC(50),WRC(50),WQC(50),NTIME,TSWTCH(15),ISWTCH                   GTR
      COMMON/COM/C(2000)                                                GTR
      COMMON/ALBET/XBETA,ZBETA,XALPHA,YALPHA                            GTR
      COMMON/STNAV/XST(7),YST(7),ZST(7),DIREQ(7),ISTDME,ISTVOR          GTR
     1,R1(40),NOYES(40),SIGMA(40)                                       GTR
      COMMON/DOUBLE/DSEED,DDS                                           GTR
      DOUBLE PRECISION DSEED,DDS                                        GTR
C                                                                       GTR
      EQUIVALENCE (C(202),NRATE)                                        GTR
      EQUIVALENCE (C(214),DTPR),(C(215),DTPLT),(C(216),DTTTY)           GTR
      EQUIVALENCE (C(220),IPR),(C(244),TIMSOF)                          GTR
      EQUIVALENCE (C(341),H0),(C(347),XE0),(C(348),YE0)                 GTR
      EQUIVALENCE (C(277),USPED0),(C(278),VSPED0),(C(279),WSPED0)       GTR
C                                                                       GTR
      DATA H0/116./,TIMSOF/60. /,TET0/10./,PSI0J/0./,PHI0J/12.7/,       GTR
     1NTIME/15/,USPED0/125./,VSPED0/0./,WSPED0/12./                     GTR
     2,TPROG/0.,60.,61.,100.,101.,160.,161.,43*600./,                   GTR
     6Q0/2*.6,2*0.,2*.6,44*0./,                                         GTR
     7WP0J/2*-.5,2*0.,2*.5,44*0./,                                      GTR
     9WR0J/2*2.86,2*0.,2*-2.86,44*0./,                                  GTR
     ETACCX/2*.179,2*.096,2*.179,2*-.206,42*.2/,                        GTR
     CTACCY/40*0.,10*0./,                                               GTR
     DTACCZ/2*-1.003,2*-.994,2*-1.003,2*-.985,42*-1./                   GTR
      DATA NRATE/20/,DTPR/400./,DTPLT/400./,DTTTY/1./,                  GTR
     1IPR/1/                                                            GTR
     2,XBETA/0./,ZBETA/0./,XALPHA/0./,YALPHA/0./                        GTR
     3,XST/7*120000./                                                   GTR
     4,YST/7*120000./                                                   GTR
     5,ZST/7*0./                                                        GTR
     6,DIREQ/7*32./                                                     GTR
     7,ISTDME/1/,ISTVOR/1/                                              GTR
      DATA DSEED/1.D0/,DDS/1.D0/,NOYES/40*0/,SIGMA/40*0./               GTR
      DATA ISWTCH/1/,TSWTCH/15*600./                                    GTR
     1,XE0/0./,YE0/0./                                                  GTR
      END                                                               GTR
      SUBROUTINE INPT                                                   GTR
      INTEGER FILE(6),GO                                                GTR
```

```
      LOGICAL SOF                                                       GT
      DIMENSION NAME(8),LNAME(4)                                        GT
C                                                                       GT
      COMMON/COM/C(2000)                                                GT
      COMMON/DEGREE/TET0,Q0(50),PSI0J,PHI0J,WP0J(50),WR0J(50)           GT
      COMMON/PROG/TACCX(50),TACCY(50),TACCZ(50),TPROG(50),              GT
     1WPC(50),WRC(50),WQC(50),NTIME,TSWTCH(15),ISWTCH                   GT
      COMMON/ALBET/XBETA,ZBETA,XALPHA,YALPHA                            GT
      COMMON/STNAV/XST(7),YST(7),ZST(7),DIREQ(7),ISTDME,ISTVOR          GT
     1,R1(40),NOYES(40),SIGMA(40)                                       GT
      COMMON/DOUBLE/DSEED,DDS                                           GT
      DOUBLE PRECISION DSEED,DDS                                        GT
C                                                                       GT
      EQUIVALENCE (C(202),NRATE)                                        GT
      EQUIVALENCE (C(214),DTPR),(C(215),DTPLT),(C(216),DTTTY)           GT
      EQUIVALENCE (C(220),IPR),(C(243),IF2),(C(244),TIMSOF)             GT
      EQUIVALENCE (C(341),H0),(C(347),XE0),(C(348),YE0)                 GT
      EQUIVALENCE (C(277),USPED0),(C(278),VSPED0),(C(279),WSPED0)       GT
C                                                                       GT
      NAMELIST/INP/FILE                                                 GT
      NAMELIST/INCN/H0,TET0,Q0,TIMSOF,PSI0J,PHI0J,WP0J,WR0J,            GT
     1TACCX,TACCY,TACCZ,NTIME,TPROG,USPED0,VSPED0,WSPED0                GT
     2,XBETA,ZBETA,XALPHA,YALPHA                                        GT
     3,XST,YST,ZST,DIREQ,ISTDME,ISTVOR                                  GT
     4,TSWTCH,XEC,YEC                                                   GT
      NAMELIST/PARM/NRATE,DTTTY,DTPR,DTPLT,IPR,DSEED,DDS,NOYES,SIGMA    GT
C                                                                       GT
      DATA NAME/4HINCN,4HPARM,4H    ,4H    ,4H    ,4H    ,4H    ,4H   /GT
  235 CONTINUE                                                          GT
      PRINT 502                                                         GT
  502 FORMAT(1H ,'TO   CONTINUE ENTER F,TO      STOP ENTER T')          GT
      READ 503,SOF                                                      GT
  503 FORMAT(L1)                                                        GT
      IF(SOF)STOP                                                       GT
      PRINT 500                                                         GT
  500 FORMAT(1H ,'ENTER DESIRED FILES IN      NAMELIST INP',/)          GT
      READ(5,INP)                                                       GT
      IF1=FILE(1)                                                       GT
      IF2=FILE(2)                                                       GT
      IF3=FILE(3)                                                       GT
      IF4=FILE(4)                                                       GT
      IF5=FILE(5)                                                       GT
      IF6=FILE(6)                                                       GT
      DO 220 I=1,2                                                      GT
      LNAME(I)=NAME(I)                                                  GT
  220 CONTINUE                                                          GT
C                                                                       GT
      IF(IF1.EQ.5)PRINT 501,LNAME                                       GT
  501 FORMAT(1H ,'ENTER      NAMELISTS ',A4,A4,'IN THIS ORDER',/)       GT
      IF(IF3.NE.0)READ(IF1,INCN)                                        GT
      IF(IF4.NE.0)READ(IF1,PARM)                                        GT
C                                                                       GT
      PRINT 504                                                         GT
  504 FORMAT(1H ,'TO RUN ENTER 1,TO MODIFY INPUT      DATA ENTER 0')    GT
      READ 505,GO                                                       GT
```

```
  505 FORMAT(I1)                                                        GTR
      IF(GO.NE.1)GOTO 235                                               GTR
      RETURN                                                            GTR
      END                                                               GTR
      SUBROUTINE INIT                                                   GTR
      DIMENSION IPL(100),IPD(100)                                       GTR
      COMMON/COM/C(2000)                                                GTR
      COMMON/DEGREE/TET0,Q0(50),PSI0J,PHI0J,WP0J(50),WR0J(50)           GTR
      COMMON/PROG/TACCX(50),TACCY(50),TACCZ(50),TPROG(50),WPC(50),      GTR
     1WRC(50),WQC(50),NTIME,TSWTCH(15),ISWTCH                           GTR
      COMMON/RK/ARK(4),BRK(4),CRK(4),QRK(100)                           GTR
C                                                                       GTR
      EQUIVALENCE (C(201),N)                                            GTR
      EQUIVALENCE (C(202),NRATE),(C(203),TIME),(C(204),TIMED)           GTR
      EQUIVALENCE (C(205),DT),(C(207),NSTEP)                            GTR
      EQUIVALENCE (C(211),TIMPR),(C(212),TIMPLT),(C(213),TIMTTY)        GTR
      EQUIVALENCE (C(214),DTPR),(C(215),DTPLT),(C(216),DTTTY)           GTR
      EQUIVALENCE (C(217),LINE),(C(218),NPRINT),(C(219),NPLOT)          GTR
      EQUIVALENCE (C(222),NSQ2)                                         GTR
      EQUIVALENCE (C(242),CRAD),(C(370),GRAV1),(C(319),THET0)           GTR
      EQUIVALENCE (C(318),PHI0),(C(320),PSI0)                           GTR
C                                                                       GTR
      GRAV1=32.17                                                       GTR
C                                                                       GTR
      ARK(1)=.5                                                         GTR
      ARK(2)=1.-1./SQRT(2.)                                             GTR
      ARK(3)=1.+1./SQRT(2.)                                             GTR
      ARK(4)=1./6.                                                      GTR
      BRK(1)=2.                                                         GTR
      BRK(2)=1.                                                         GTR
      BRK(3)=1.                                                         GTR
      BRK(4)=2.                                                         GTR
      CRK(1)=ARK(1)                                                     GTR
      CRK(2)=ARK(2)                                                     GTR
      CRK(3)=ARK(3)                                                     GTR
      CRK(4)=ARK(1)                                                     GTR
      DO 229 I=1,100                                                    GTR
  229 QRK(I)=0.                                                         GTR
C                                                                       GTR
      NSQ2=1                                                            GTR
C                                                                       GTR
      PI=4.*ATAN(1.)                                                    GTR
      CRAD=180./PI                                                      GTR
      THET0=TET0/CRAD                                                   GTR
      PSI0=PSI0J/CRAD                                                   GTR
      PHI0=PHI0J/CRAD                                                   GTR
      DO 248 I=1,NTIME                                                  GTR
      WPC(I)=WP0J(I)/CRAD                                               GTR
      WQC(I)=Q0(I)/CRAD                                                 GTR
  248 WRC(I)=WR0J(I)/CRAD                                               GTR
C                                                                       GTR
      IPL(1)=203                                                        GTR
      IPD(1)=204                                                        GTR
      N=1                                                               GTR
      C(1)=IPL(1)                                                       GTR
```

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      C(101)=IPD(1)                                                          GT
      TIME=0.                                                                GT
      TIMED=1.                                                               GT
      NSTEP=0                                                                GT
      NRAT=NRATE                                                             GT
       DT=1./FLOAT(NRAT)                                                     GT
C                                                                            GT
      NPRINT=0                                                               GT
       NPLOT=0                                                               GT
       LINE=60                                                               GT
       TIMPR=DTPR-.5*DT                                                      GT
       TIMPLT=DTPLT-.5*DT                                                    GT
      TIMTTY=DTTTY-.5*DT                                                     GT
      IF(DTTTY.GT.50.)       TIMTTY=1000.                                    GT
C                                                                            GT
      RETURN                                                                 GT
      END                                                                    GT
      SUBROUTINE ERROR                                                       GT
      PRINT 507                                                              GT
  507 FORMAT(1H ,'RUNNING NOW',/)                                            GT
      RETURN                                                                 GT
      END                                                                    GT
      SUBROUTINE DYNAMI                                                      GT
      DIMENSION IPL(100),IPD(100)                                            GT
      COMMON/COM/C(2000)                                                     GT
      EQUIVALENCE (C(201),N)                                                 GT
      EQUIVALENCE (C(205),DT)                                                GT
      EQUIVALENCE (C(311),TET),(C(319),THET0),(C(312),PHI)                   GT
      EQUIVALENCE (C(318),PHI0),(C(310),PSI),(C(320),PSI0)                   GT
      EQUIVALENCE (C(334),XE),(C(335),YE),(C(336),ZE)                        GT
      EQUIVALENCE (C(341),H0),(C(343),HM),(C(347),XE0),(C(348),YE0)          GT
      EQUIVALENCE (C(271),USPEED),(C(277),USPED0),(C(272),VSPEED)            GT
      EQUIVALENCE (C(278),VSPED0),(C(273),WSPEED),(C(279),WSPED0)            GT
C                                                                            GT
      N=N+1                                                                  GT
       IPL(N)=310                                                            GT
       IPD(N)=314                                                            GT
      N=N+1                                                                  GT
       IPL(N)=311                                                            GT
       IPD(N)=315                                                            GT
      N=N+1                                                                  GT
       IPL(N)=312                                                            GT
       IPD(N)=316                                                            GT
      N=N+1                                                                  GT
       IPL(N)=271                                                            GT
       IPD(N)=274                                                            GT
      N=N+1                                                                  GT
       IPL(N)=272                                                            GT
       IPD(N)=275                                                            GT
      N=N+1                                                                  GT
       IPL(N)=273                                                            GT
       IPD(N)=276                                                            GT
      N=N+1                                                                  GT
       IPL(N)=334                                                            GT
       IPD(N)=337                                                            GT
```

```
      N=N+1                                                              GTR
       IPL(N)=335                                                        GTR
       IPD(N)=338                                                        GTR
      N=N+1                                                              GTR
       IPL(N)=336                                                        GTR
       IPD(N)=339                                                        GTR
C                                                                        GTR
      TET=THET0                                                          GTR
      PSI=PSI0                                                           GTR
      PHI=PHI0                                                           GTR
      XE=XE0                                                             GTR
      YE=YE0                                                             GTR
      ZE=-H0                                                             GTR
      HM=H0                                                              GTR
C                                                                        GTR
      USPEED=USPED0                                                      GTR
      VSPEED=VSPED0                                                      GTR
      WSPEED=WSPED0                                                      GTR
C                                                                        GTR
      DO 111 I=2,N                                                       GTR
      C(I)=IPL(I)                                                        GTR
  111 C(100+I)=IPD(I)                                                    GTR
C                                                                        GTR
      RETURN                                                             GTR
      END                                                                GTR
      SUBROUTINE LOGIC                                                   GTR
      COMMON/COM/C(2000)                                                 GTR
      COMMON/PROG/TACCX(50),TACCY(50),TACCZ(50),IPROG(50),               GTR
     1WPC(50),WRC(50),WQC(50),NTIME,TSWTCH(15),ISWTCH                    GTR
      EQUIVALENCE (C(302),WQ),(C(303),WR),(C(301),WP)                    GTR
      EQUIVALENCE (C(531),ACCX),(C(532),ACCY),(C(533),ACCZ)              GTR
      EQUIVALENCE (C(203),TIME),(C(311),TET)                             GTR
      EQUIVALENCE (C(312),PHI),(C(272),VSPEED),(C(205),DT)               GTR
      IF(TIME.LT.TSWTCH(ISWTCH))GOTO 11                                  GTR
      IF(ISWTCH.EQ.1)GOTO 12                                             GTR
      IF(ISWTCH.EQ.2)GOTO 13                                             GTR
      PHI=0.                                                             GTR
      TET=-.1745                                                         GTR
      ISWTCH=ISWTCH+1                                                    GTR
      GOTO 11                                                            GTR
   13 PHI=12.7*.01745                                                    GTR
      TET=.1745                                                          GTR
      ISWTCH=ISWTCH+1                                                    GTR
      GOTO 11                                                            GTR
   12 PHI=0.                                                             GTR
      TET=.096                                                           GTR
      ISWTCH=ISWTCH+1                                                    GTR
   11 CONTINUE                                                           GTR
C***FOR THIS N.L. MODEL TRANSITION BETWEEN COMPUTATIONALLY PREDICTED     GTR
C***STEADY STATES WILL ANYWAY BE ARTIFICIAL. THUS, THE TSWTCH-OPTION     GTR
C***IS DEFFERRED AND ONLY THE FIRST SQUINT-SEGMENT IS USED IN EACH RUN.  GTR
C***RESULTS OF ALL RUNS APPEND TO EACH OTHER ON FILE 10('DISP MOD'-      GTR
C***OPTION OF FILEDEF-BEFORE THE CONSECUTIVE RUNS OF THE JOB).          GTR
C***THE CREATED FILE HAS ALL DATA-VARIABLES OF A GIVEN INSTANT AS A     GTR
C***RECORD.IT'S COMPATIBLE WITH APL-LINPLOT(BLANKS BETWEEN VALUES),     GTR
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```
C***AND A SEPARATE PROGRAM CONVERTS IT TO A TIME-VECTOR-RECORD FILE.     GT
      WQ=SQUINT(TIME,TPROG,WQC,NTIME,1)                                  GT
      WP=SQUINT(TIME,TPROG,WPC,NTIME,1)                                  GT
      WR=SQUINT(TIME,TPROG,WRC,NTIME,1)                                  GT
      ACCX=SQUINT(TIME,TPROG,TACCX,NTIME,1)                              GT
      ACCY=SQUINT(TIME,TPROG,TACCY,NTIME,1)                              GT
      ACCZ=SQUINT(TIME,TPROG,TACCZ,NTIME,1)                              GT
      RETURN                                                             GT
      END                                                                GT
      SUBROUTINE DYNAM                                                   GT
      COMMON/COM/C(2000)                                                 GT
C                                                                        GT
      EQUIVALENCE (C(302),WQ),(C(311),TET),(C(315),DTET)                 GT
      EQUIVALENCE (C(321),VX),(C(323),VZ)                                GT
      EQUIVALENCE (C(334),XE),(C(336),ZE),(C(337),XED),(C(339),ZED)      GT
      EQUIVALENCE (C(351),CEB11)                                         GT
      EQUIVALENCE (C(353),CEB13),(C(357),CEB31),(C(359),CEB33)           GT
      EQUIVALENCE (C(310),PSI),(C(312),PHI),(C(314),DPSI),(C(316),DPHI)  GT
      EQUIVALENCE (C(301),WP),(C(303),WR)                                GT
      EQUIVALENCE (C(322),VY),(C(335),YE),(C(338),YED)                   GT
      EQUIVALENCE (C(439),CSF),(C(440),SNF),(C(441),CST),(C(442),SNT)    GT
      EQUIVALENCE (C(352),CEB12),(C(354),CEB21),(C(355),CEB22)           GT
      EQUIVALENCE (C(356),CEB23),(C(358),CEB32)                          GT
      EQUIVALENCE (C(531),ACCX),(C(532),ACCY),(C(533),ACCZ)              GT
      EQUIVALENCE (C(271),USPEED),(C(272),VSPEED),(C(273),WSPEED)        GT
      EQUIVALENCE (C(274),DUSPED),(C(275),DVSPED),(C(276),DWSPED)        GT
      EQUIVALENCE (C(370),GRAV1)                                         GT
C                                                                        GT
      DPSI=(WR*CSF+WQ*SNF)/CST                                           GT
      DTET=WQ*CSF-WR*SNF                                                 GT
      DPHI=WP+DPSI*SNT                                                   GT
      CALL DBTOI(USPEED,VSPEED,WSPEED,CEB11,CEB12,CEB13                  GT
     1,CEB21,CEB22,CEB23,CEB31,CEB32,CEB33,VX,VY,VZ)                     GT
      XED=VX                                                             GT
      ZED=VZ                                                             GT
      YED=VY                                                             GT
      DUSPED=-WQ*WSPEED+WR*VSPEED-GRAV1*SNT     +ACCX*GRAV1              GT
C*****DVSPED=-WR*USPEED+WP*WSPEED+GRAV1*CST*SNF+ACCY*GRAV1-ASSUME COORD.GT
      DVSPED=0.                                                          GT
      DWSPED=+WQ*USPEED-WP*VSPEED+GRAV1*CST*CSF+ACCZ*GRAV1               GT
C                                                                        GT
C                                                                        GT
      RETURN                                                             GT
      END                                                                GT
      SUBROUTINE FINISH                                                  GT
      COMMON/COM/C(2000)                                                 GT
      COMMON/REC/A3(2000,20)                                             GT
C                                                                        GT
      EQUIVALENCE (C(203),TIME),(C(217),LINE),(C(218),NPRINT)            GT
      EQUIVALENCE (C(219),NPLOT),(C(220),IPR),(C(243),IF2),(C(242),CRAD) GT
      EQUIVALENCE (C(212),TIMPLT)                                        GT
C                                                                        GT
      ENTRY FINT                                                         GT
      WRITE(IF2,516)                                                     GT
  516 FORMAT(1H ,'TIME IS OVER',///)                                     GT
```

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C                                                                       GTR
      IF(NPLOT.LT.2)GOTO 518                                            GTR
      DO 121 I=1,NPLOT                                                  GTR
  121 WRITE(10,531)(A3(I,J),J=1,16)                                     GTR
  531 FORMAT(1H ,16(F9.2,X))                                            GTR
      ENDFILE 10                                                        GTR
      WRITE(IF2,517)NPLOT                                               GTR
  517 FORMAT(1H ,I15)                                                   GTR
  518 CONTINUE                                                          GTR
      RETURN                                                            GTR
      END                                                               GTR
      SUBROUTINE OUTPT                                                  GTR
      COMMON/COM/C(2000)                                                GTR
      COMMON/RUNOUT/DAN                                                 GTR
      COMMON/REC/A3(2000,20)                                            GTR
      DIMENSION RDME(7),VOR(7)                                          GTR
      COMMON/ALBET/XBETA,ZBETA,XALPHA,YALPHA                            GTR
      COMMON/STNAV/XST(7),YST(7),ZST(7),DIREQ(7),ISTDME,ISTVOR          GTR
     1,R1(40),NOYES(40),SIGMA(40)                                       GTR
      EQUIVALENCE (C(336),ZE)                                           GTR
      EQUIVALENCE (C(203),TIME),(C(211),TIMPR),(C(212),TIMPLT)          GTR
      EQUIVALENCE (C(213),TIMTTY),(C(214),DTPR),(C(215),DTPLT)          GTR
      EQUIVALENCE (C(216),DTTTY),(C(217),LINE),(C(218),NPRINT)          GTR
      EQUIVALENCE (C(219),NPLOT),(C(242),CRAD),(C(243),IF2)             GTR
      EQUIVALENCE (C(302),WQ),(C(321),VX),(C(323),VZ),(C(334),XE)       GTR
      EQUIVALENCE (C(343),HM),(C(311),TET)                              GTR
      EQUIVALENCE (C(310),PSI),(C(312),PHI)                             GTR
      EQUIVALENCE (C(301),WP),(C(303),WR),(C(322),VY),(C(335),YE)       GTR
      EQUIVALENCE (C(531),ACCX),(C(532),ACCY),(C(533),ACCZ)             GTR
      EQUIVALENCE (C(271),USPEED),(C(272),VSPEED),(C(273),WSPEED)       GTR
C                                                                       GTR
C                                                                       GTR
      WPJ=CRAD*WP+NOYES(1)*SIGMA(1)*R1(1)                               GTR
      WQJ=CRAD*WQ+NOYES(2)*SIGMA(2)*R1(2)                               GTR
      WRJ=CRAD*WR+NOYES(3)*SIGMA(3)*R1(3)                               GTR
      PSIJ=CRAD*PSI+NOYES(4)*SIGMA(4)*R1(4)                             GTR
      THETJ=CRAD*TET+NOYES(5)*SIGMA(5)*R1(5)                            GTR
      PHIJ=CRAD*PHI+NOYES(6)*SIGMA(6)*R1(6)                             GTR
      VAIR=SQRT(USPEED**2+VSPEED**2+WSPEED**2)+NOYES(7)*SIGMA(7)*R1(7)  GTR
      VRP=VSPEED+WR*XBETA-WP*ZBETA                                      GTR
      USPD=USPEED                                                       GTR
      BETA=ATAN2(VRP,USPD)                                              GTR
      BETAJ=CRAD*BETA+NOYES(8)*SIGMA(8)*R1(8)                           GTR
      WQR=WSPEED-WQ*XALPHA+WP*YALPHA                                    GTR
      ALPHA=ATAN2(WQR,USPD)                                             GTR
      ALPHAJ=CRAD*ALPHA+NOYES(9)*SIGMA(9)*R1(9)                         GTR
      HM=-ZE+NOYES(10)*SIGMA(10)*R1(10)                                 GTR
      DO 301 I=1,ISTDME                                                 GTR
  301 RDME(I)=SQRT((XE-XST(I))**2+(YE-YST(I))**2+(ZE-ZST(I))**2)+       GTR
     1NOYES(10+I)*SIGMA(10+I)*R1(10+I)                                  GTR
      DO 302 I=1,ISTVOR                                                 GTR
      YVOR=YE-YST(I)                                                    GTR
      XVOR=XE-XST(I)                                                    GTR
      REQ=DIREQ(I)/CRAD                                                 GTR
      RUNITX=COS(REQ)                                                   GTR
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      RUNITY=SIN(BEQ)                                                    GT
      VCOS=ABS((XVOR*RUNITX+YVOR*RUNITY)/SQRT(XVOR**2+YVOR**2))          GT
      RVOR1=ARCOS(VCOS)                                                  GT
      RVOR=CRAD*RVOR1+NOYES(10+ISTDME+I)*SIGMA(10+ISTDME+I)*             GT
     1R1(10+ISTDME+I)                                                    GT
  302 VOR(I)=SATF(RVOR,10.)                                              GT
      VXY=SQRT(VX*VX+VY*VY)                                              GT
      VZN=-VZ                                                            GT
      GAMV=ATAN2(VZN,VXY)                                                GT
      GAMVJ=CRAD*GAMV                                                    GT
      GAMH=ATAN2(VY,VX)                                                  GT
      GAMHJ=CRAD*GAMH                                                    GT
      ACCX=ACCX+NOYES(10+ISTDME+ISTVOR+1)*SIGMA(10+ISTDME+ISTVOR+1)*     GT
     1R1(10+ISTDME+ISTVOR+1)                                             GT
      ACCY=ACCY+NOYES(10+ISTDME+ISTVOR+2)*SIGMA(10+ISTDME+ISTVOR+2)*     GT
     1R1(10+ISTDME+ISTVOR+2)                                             GT
      ACCZ=ACCZ+NOYES(10+ISTDME+ISTVOR+3)*SIGMA(10+ISTDME+ISTVOR+3)*     GT
     1R1(10+ISTDME+ISTVOR+3)                                             GT
C***NOW,IF TRIGGERED-CONTAMINATION BY NOISE;IF NOT-BYPASSED.             GT
C                                                                        GT
C***OUTPUT OPTIONS:                                                      GT
C***  1.SHORT(TERMINAL) PRINTOUT;                                        GT
C***  2.LONG PRINTOUT OF FIRST BUNCH,SECOND OR BOTH;                     GT
C***  3.CREATION OF 1SEC-INTERVAL-FILE OF DATA(SAME AS FLIGHT FILE)-     GT
C***    -TO BE PRINTED,PLOTTED OR FURTHER PROCESSED.                     GT
C                                                                        GT
      IF(TIME.GT.0..AND.DAN.LT.1.)GOTO 879                               GT
      PRINT 508                                                          GT
      WRITE(IF2,511)TIME,VAIR,GAMVJ,GAMHJ,HM,XE,YE,PSIJ,THETJ,           GT
     1PHIJ,VOR(1),RDME(1),ALPHAJ,BETAJ                                   GT
  879 CONTINUE                                                           GT
      IF(TIME.LE.TIMPR)GOTO 241                                          GT
      IF(LINE.NE.60)GOTO 259                                             GT
      WRITE(IF2,508)                                                     GT
  508 FORMAT(1H1,' TIME      VAIR      GAMVJ     GAMEJ       HM         XE     GT
     1YE     PSIJ     THETJ     PHIJ      VOR(1)    RDME(1)   ALPHAJ    BETAJ') GT
       NPRINT=NPRINT+1                                                   GT
       LINE=1                                                            GT
  259 CONTINUE                                                           GT
      WRITE(IF2,511)TIME,VAIR, GAMVJ,GAMHJ,HM,XE,YE,PSIJ,THETJ,PHIJ,    GT
     1VOR(1),RDME(1),ALPHAJ,BETAJ                                        GT
  511 FORMAT(1H ,5F7.1,2F10.1,4F7.1,F11.1,2F7.1)                         GT
       NPRINT=NPRINT+1                                                   GT
      TIMPR=TIMPR+DTPR                                                   GT
       LINE=LINE+1                                                       GT
  241   IF(TIME.LE.TIMPLT.OR.NPLOT.GE.2000)GOTO 247                      GT
       NPLOT=NPLOT+1                                                     GT
      A3(NPLOT,1)=TIME                                                   GT
      A3(NPLOT,2)=WPJ                                                    GT
      A3(NPLOT,3)=WQJ                                                    GT
      A3(NPLOT,4)=WRJ                                                    GT
      A3(NPLOT,5)=ACCX                                                   GT
      A3(NPLOT,6)=ACCY                                                   GT
      A3(NPLOT,7)=ACCZ                                                   GT
      A3(NPLOT,8)=HM                                                     GT
```

```
      A3(NPLOT,9)=VAIR                                                  GTR
      A3(NPLOT,10)=PSIJ                                                 GTR
      A3(NPLOT,11)=THETJ                                                GTR
      A3(NPLOT,12)=PHIJ                                                 GTR
      A3(NPLOT,13)=VOR(1)                                               GTR
      A3(NPLOT,14)=RDME(1)                                              GTR
      A3(NPLOT,15)=ALPHAJ                                               GTR
      A3(NPLOT,16)=BETAJ                                                GTR
       TIMPLT=TIMPLT+DTPLT                                              GTR
  247    IF(TIME.LE.TIMTTY)GOTO 240                                     GTR
      IF(TIME.LT.(1.5*DTTTY))PRINT 510                                  GTR
  510 FORMAT(1H1,' TIME        VAIR      GAMVJ      GAMHJ        XE       YE GTR
     1    HM')                                                          GTR
      PRINT 513,TIME,VAIR,GAMVJ,GAMHJ,XE,YE,HM                         GTR
  513 FORMAT(1H ,7F10.1)                                                GTR
       TIMTTY=TIMTTY+DTTTY                                              GTR
  240 CONTINUE                                                          GTR
C                                                                       GTR
      RETURN                                                            GTR
      END                                                               GTR
      FUNCTION SATF(X11,XM11)                                           GTR
      SATF=SIGN(AMIN1(ABS(X11),XM11),X11)                               GTR
      RETURN                                                            GTR
      END                                                               GTR
      SUBROUTINE RCTAT                                                  GTR
      COMMON/COM/C(2000)                                                GTR
      EQUIVALENCE (C(311),TET),(C(351),CEB11),(C(353),CEB13)            GTR
      EQUIVALENCE (C(357),CEB31),(C(359),CEB33)                         GTR
      EQUIVALENCE (C(441),CST),(C(442),SNT)                             GTR
      EQUIVALENCE (C(310),PSI),(C(312),PHI),(C(352),CEB12)              GTR
      EQUIVALENCE (C(354),CEB21),(C(355),CEB22),(C(356),CEB23)          GTR
      EQUIVALENCE (C(358),CEB32),(C(443),CSP),(C(444),SNP)              GTR
      EQUIVALENCE (C(439),CSF),(C(440),SNF)                             GTR
C                                                                       GTR
      SNT=SIN(TET)                                                      GTR
      CST=COS(TET)                                                      GTR
      SNP=SIN(PSI)                                                      GTR
      CSP=COS(PSI)                                                      GTR
      SNF=SIN(PHI)                                                      GTR
      CSF=COS(PHI)                                                      GTR
C                                                                       GTR
      CEB11=CST*CSP                                                     GTR
      CEB13=-SNT                                                        GTR
      CEB31=+SNT*CSF*CSP+SNF*SNP                                        GTR
      CEB33=CST*CSF                                                     GTR
      CEB12=CST*SNP                                                     GTR
      CEB21=SNF*SNT*CSP-CSF*SNP                                         GTR
      CEB22=SNF*SNT*SNP+CSF*CSP                                         GTR
      CEB23=SNF*CST                                                     GTR
      CEB32=CSF*SNT*SNP-SNF*CSP                                         GTR
      RETURN                                                            GTR
      END                                                               GTR
      SUBROUTINE DITOB(XI,YI,ZI,A11,A12,A13,A21,A22,A23,A31,A32,A33,    GTR
     1XO,YO,ZO)                                                         GTR
      XO=A11*XI+A13*ZI+A12*YI                                           GTR
```

```
      ZO=A31*XI+A33*ZI+A32*YI                                           GT
      YO=A21*XI+A22*YI+A23*ZI                                           GT
      RETURN                                                            GT
      ENTRY DBTCI(XI,YI,ZI,A11,A12,A13,A21,A22,A23,A31,A32,A33,         GT
     1XO,YO,ZO)                                                         GT
      XO=A11*XI+A31*ZI+A21*YI                                           GT
      ZO=A13*XI+A33*ZI+A23*YI                                           GT
      YO=A12*XI+A22*YI+A32*ZI                                           GT
      RETURN                                                            GT
      END                                                               GT
      SUBROUTINE RKG                                                    GT
      DIMENSION IPL(100),IPD(100)                                       GT
      COMMON/COM/C(2000)                                                GT
      COMMON/RK/ARK(4),BRK(4),CRK(4),QRK(100)                           GT
C                                                                       GT
      EQUIVALENCE (C(201),N)                                            GT
      EQUIVALENCE (C(205),H),(C(241),J)                                 GT
C                                                                       GT
      DO 100 I=1,N                                                      GT
      IL=C(I)                                                           GT
      ID=C(100+I)                                                       GT
      X1=C(ID)*H                                                        GT
      X2=(X1-BRK(J)*QRK(I))*ARK(J)                                      GT
      C(IL)=C(IL)+X2                                                    GT
100   QRK(I)=QRK(I)+3.*X2-CRK(J)*X1                                     GT
C                                                                       GT
      RETURN                                                            GT
      END                                                               GT
      FUNCTION SQUINT(X,TABX,TABY,NTAB,N)                               GT
      DIMENSION TABX(NTAB),TABY(NTAB)                                   GT
      IF(NTAB.NE.1)GOTO 1                                               GT
      SQUINT=TABY(NTAB)                                                 GT
      RETURN                                                            GT
    1 IF(X-TABX(N))2,3,4                                                GT
    2  N=N-1                                                            GT
      IF(N)9,9,1                                                        GT
    3  SQUINT=TABY(N)                                                   GT
      FACTOR=0.                                                         GT
      RETURN                                                            GT
    4  IF((N+1).GT.NTAB)GOTO 10                                         GT
      IF(X-TABX(N+1))5,6,7                                              GT
    6  N=N+1                                                            GT
      GOTO 3                                                            GT
    7  N=N+1                                                            GT
      GOTO 4                                                            GT
    5  FACTOR=(X-TABX(N))/(TABX(N+1)-TABX(N))                           GT
       SQUINT=(TABY(N+1)-TABY(N))*FACTOR+TABY(N)                        GT
      RETURN                                                            GT
    9  PRINT 1000,X,TABX(1)                                             GT
      Y=SQRT(-1.)                                                       GT
      STOP                                                              GT
 1000 FORMAT(1H ,10('$'),'SQUINT UNDERFLOW - INPUT =',E15.8 ,'  LESS THAGT
     1N  FIRST  ARG. TABLE      ENTRY( ',E15.8 ,' ) ')                 GT
   10   PRINT 2000,X,TABX(NTAB)                                         GT
      Y=SQRT(-1.)                                                       GT
```

FILE: GTRAJ1 FORTRAN A1 PRINCETON UNIVERSITY TIME-SHARING SYSTEM

```
      STOP                                                                  GTR
 2000 FORMAT(1H ,10('$'), 'SQUINT OVERFLOW -INPUT =',E15.8 ,'  GREATER  GTR
     1 THAN  LAST  ARG. TABLE      ENTRY (',E15.8 ,' ) ' )                 GTR
      END                                                                   GTR
```

FILE: OPTFILT FORTRAN A PRINCETON UNIVERSITY TIME-SHARING

```
C*                                                                      C
C*OPTIMAL FILTERING PROGRAM                                             C
C*                                                                      C
      IMPLICIT REAL*8(A-H,O-$)                                          C
      REAL*4 PREDCT(6)                                                  C
      DIMENSION SUM(6),H112(11,6),H111(6,6)                             C
      COMMON/DAT0/S2LIAC,S2XYZR,TIMSOF,X00(11),S2WIND,S2WNDZ,S2WNDY     C
     1,S2V,S2ALF,S2BET,S2H,S2DME,S2VOR,S2BDME,S2ZR,PERCNT,OMEGA,AGLOBE  C
     4,OUTL1,OUTL2,S2QA,S2QB                                            C
     2,EPS2,TLAM0,SMEW0,XST,YST,ZST,DIREQ,KDME(20),NDME1(20),NDME2(20)  C
     3,KDME2(20) ,NXP,NRATE,NSTEP,IDGT,ISTDME,ISTVOR,SOF               C
      LOGICAL GO,SOF                                                    C
      NAMELIST/INP/FILE                                                 C
      INTEGER FILE(2)                                                   C
      NAMELIST/OK/GO                                                    C
      NAMELIST/DAT/SOF,NXP,S2LIAC,S2XYZR,NRATE,TIMSOF,X00,NSTEP,IDGT    C
     1,S2V,S2ALF,S2BET,S2H,S2DME,S2VOR,PERCNT,OMEGA,AGLOBE              C
     4,OUTL1,OUTL2,S2QA,S2QB                                            C
     2,EPS2,ISTDME,ISTVOR,XST,YST,ZST,DIREQ,KDME,NDME1,NDME2,S2WIND     C
     3,TLAM0,SMEW0,S2WNDZ,S2BDME,S2ZR,S2WNDY,KDME2                      C
      DIMENSION P(11,11),P0(11,11),HB(6,11),X0(11),XOUT(11)             C
     1,RES(6),RK(6,6),HBT(11,6),PHT(11,6),HPHT(6,6),HPHTR(6,6)          C
     2,HPHTRI(6,6),WKAREA(110),CKALM(11,6),DELX(11,1),RES1(6,1)         C
     3,XPLUS(11),AIDEN(11,11),CH(11,11),UNMKH(11,11),PPLUS(11,11)       C
     4,CKALMT(6,11),UNMKHT(11,11),STABK1(11,11),STABK2(11,11)           C
     5,STABK3(6,11),STABK4(11,11)                                       C
      DIMENSION XST(7),YST(7),ZST(7),DIREQ(7)                           C
     1,XST7(7),YST7(7),ZST7(7),DIREQ7(7)                                C
C***                                                                    C
      DEFINE FILE 12(60,2112,L,KSTEPA)                                  C
C***                                                                    C
    1 CONTINUE                                                          C
      PRINT 1002                                                        C
 1002 FORMAT(1H ,'TYPE &INP FILE= &END')                                C
      READ(5,INP)                                                       C
      INF1=FILE(1)                                                      C
      INF2=FILE(2)                                                      C
      PRINT 2000,FILE                                                   C
 2000 FORMAT(2I10)                                                      C
      PRINT 1004                                                        C
 1004 FORMAT(1H ,'TYPE &DAT DATA= &END')                                C
      READ(INF1,DAT)                                                    C
      IF(SOF)GOTO 92                                                    C
      PRINT 1003                                                        C
 1003 FORMAT(1H ,'IF EVERYTHING O.K. TYPE &OK GO=.TRUE.&END')           C
      GO=.TRUE.                                                         C
      READ(5,OK)                                                        C
      IF(GO)GOTO 10                                                     C
      GOTO 1                                                            C
   10 CONTINUE                                                          C
C***                                                                    C
      DO 331 I=1,6                                                      C
  331 SUM(I)=0.0D0                                                      C
C***                                                                    C
      PI=4.0D0*DATAN(1.0D0)                                             C
```

```
      CRAD=180.0D0/PI                                                   OP
      DO 17 I=1,NXP                                                     OP
   17 X0(I)=X00(I)                                                      OP
      KSTEP=0                                                           OP
      KSTEP1=0                                                          OP
      DO 101 I=1,NXP                                                    OP
      DO 102 J=1,NXP                                                    OP
      AIDEN(I,J)=0.0D0                                                  OP
  102 P0(I,J)=0.0D0                                                     OP
  101 CONTINUE                                                          OP
C******                                                                 OP
      DO 109 I=1,NXP                                                    OP
  109 AIDEN(I,I)=1.0D0                                                  OP
      DO 104 I=1,6                                                      OP
      DO 105 J=1,6                                                      OP
  105 RK(I,J)=0.0D0                                                     OP
  104 CONTINUE                                                          OP
      RK(1,1)=S2V                                                       OP
      RK(2,2)=S2ALP                                                     OP
      RK(3,3)=S2BET                                                     OP
      RK(4,4)=S2H                                                       OP
      RK(5,5)=S2DME                                                     OP
      RK(6,6)=S2DME                                                     OP
C***                                                                    OP
      DO 461 I=1,7                                                      OP
      XST7(I)=XST(I)                                                    OP
      YST7(I)=YST(I)                                                    OP
      ZST7(I)=ZST(I)                                                    OP
  461 DIREQ7(I)=DIREQ(I)                                                OP
      ISTVO7=ISTVOR                                                     OP
      ISTDM7=ISTDME                                                     OP
      NRAT7=NRATE                                                       OP
      TIMS7=TIMSOF                                                      OP
      NXP7=NXP                                                          OP
      S2LI7=S2LIAC                                                      OP
C***                                                                    OP
      IDME2=1                                                           OP
      IDME=1                                                            OP
  301 CONTINUE                                                          OP
      KSTEP=KSTEP+1                                                     OP
      KSTEP1=KSTEP1+1                                                   OP
C*                                                                      OP
      IFLAG=1                                                           OP
C***                                                                    OP
      IF(KDME(IDME).GT.KSTEP)GOTO 807                                   OP
C*                                                                      OP
      DO 817 I=1,NXP7                                                   OP
      DO 817 J=1,NXP7                                                   OP
  817 IF(I.NE.J)P0(I,J)=0.0D0                                           OP
      IFLAG=5                                                           OP
C*                                                                      OP
      XST7(1)=XST(NDME1(IDME))                                          OP
      YST7(1)=YST(NDME1(IDME))                                          OP
      ZST7(1)=ZST(NDME1(IDME))                                          OP
      IDME=IDME+1                                                       OP
```

```
  807 CONTINUE                                                          (
C*                                                                      (
      IF(KDME2(IDME2).GT.KSTEP)GOTO 827                                 (
      DO 828 I=1,NXP7                                                   (
      DO 828 J=1,NXP7                                                   (
  828 IF(I.NE.J)P0(I,J)=0.0D0                                           (
      IFLAG=5                                                           (
      XST7(2)=XST(NDME2(IDME2))                                         (
      YST7(2)=YST(NDME2(IDME2))                                         (
      ZST7(2)=ZST(NDME2(IDME2))                                         (
      IDME2=IDME2+1                                                     (
  827 CONTINUE                                                          (
C*                                                                      (
C*CALLING THE PROPAGATION-BETWEEN-MEASUREMENTS SUBROUTINE               (
C***                                                                    (
      CALL PROP27(TIMS7,PERCNT,OMEGA,AGLOBE,EPS2,S2WNDY,TLAM0           (
     1,SMEW0,S2WIND,S2WNDZ,X0,P0,XST7,YST7,ZST7,DIREQ7,S2ZR,S2BDME      (
     3,OUTL1,OUTL2,S2QA,S2QB                                            (
     2,S2LI7,S2XYZR,XOUT,P,HB,RES,IFLAG,NRAT7,NXP7,ISTDM7,ISTVO7,KSTEP) (
      DO 201 I=1,6                                                      (
      DO 202 J=1,NXP                                                    (
  202 HBT(J,I)=HB(I,J)                                                  (
  201 CONTINUE                                                          (
      CALL VMULFF(P,HBT,NXP,NXP,6,NXP,NXP,PHT,NXP,IER1)                 (
      CALL VMULFF(HB,PHT,6,NXP,6,6,NXP,HPHT,6,IER2)                     (
      DO 211 I=1,6                                                      (
      DO 212 J=1,6                                                      (
  212 HPHTR(I,J)=HPHT(I,J)+RK(I,J)                                      (
  211 CONTINUE                                                          (
C***                                                                    (
      DO 341 I=1,6                                                      (
  341 SUM(I)=SUM(I)+HPHTR(I,I)                                          (
C***                                                                    (
      CALL LINV1F(HPHTR,6,6,HPHTRI,IDGT,WKAREA,IER3)                    (
      CALL VMULFF(PHT,HPHTRI,NXP,6,6,NXP,6,CKALM,NXP,IER4)              (
      DO 221 I=1,6                                                      (
  221 RES1(I,1)=RES(I)                                                  (
      CALL VMULFF(CKALM,RES1,NXP,6,1,NXP,6,DELX,NXP,IER5)               (
      DO 231 I=1,NXP                                                    (
  231 XPLUS(I)=XOUT(I)+DELX(I,1)                                        (
      CALL VMULFF(CKALM,HB,NXP,6,NXP,NXP,6,CH,NXP,IER6)                 (
      DO 241 I=1,NXP                                                    (
      DO 242 J=1,NXP                                                    (
  242 UNMKH(I,J)=AIDEN(I,J)-CH(I,J)                                     (
  241 CONTINUE                                                          (
C-OLD CALL VMULFF(UNMKH,P,NXP,NXP,NXP,NXP,NXP,PPLUS,NXP,IER7)          (
      DO 281 I=1,NXP                                                    (
      DO 281 J=1,NXP                                                    (
  281 UNMKHT(J,I)=UNMKH(I,J)                                            (
      DO 283 I=1,NXP                                                    (
      DO 283 J=1,6                                                      (
  283 CKALMT(J,I)=CKALM(I,J)                                            (
      CALL VMULFF(P,UNMKHT,NXP,NXP,NXP,NXP,NXP,STABK1,NXP,IER7)         (
      CALL VMULFF(UNMKH,STABK1,NXP,NXP,NXP,NXP,NXP,STABK2,NXP,IER8)     (
      CALL VMULFF(RK,CKALMT,6,6,NXP,6,6,STABK3,6,IER9)                  (
```

```
      CALL VMULFF(CKALM,STABK3,NXP,6,NXP,NXP,6,STABK4,NXP,IER10)        OP
      DO 282 I=1,NXP                                                    OP
      DO 282 J=1,NXP                                                    OP
  282 PPLUS(I,J)=STABK2(I,J)+STABK4(I,J)                                OP
C***                                                                    OP
C***                                                                    OP
      IF(KSTEP1.LT.5)GOTO 253                                           OP
      KSTEP1=0                                                          OP
      DO 251 I=1,NXP                                                    OP
      DO 252 J=1,NXP                                                    OP
      IF(I.LE.J)GOTO 252                                                OP
      PPLUS(I,J)=.5D0*(PPLUS(I,J)+PPLUS(J,I))                           OP
      PPLUS(J,I)=PPLUS(I,J)                                             OP
  252 CONTINUE                                                          OP
  251 CONTINUE                                                          OP
  253 CONTINUE                                                          OP
C******                                                                 OP
      DO 741 I=1,NXP                                                    OP
  741 XO(I)=XPLUS(I)                                                    OP
      DO 742 I=1,NXP                                                    OP
      DO 742 J=1,NXP                                                    OP
  742 PO(I,J)=PPLUS(I,J)                                                OP
C***                                                                    OP
      KSTEPA=KSTEP                                                      OP
C***                                                                    OP
      WRITE(12'KSTEPA)(XPLUS(I),I=1,NXP)                                OP
     1,(XOUT(I),I=1,NXP),((PPLUS(I,J),I=1,NXP),J=1,NXP)                 OP
     2,((P(I,J),I=1,NXP),J=1,NXP)                                       OP
C***                                                                    OP
      IF(KSTEP.EQ.NSTEP)GOTO 311                                        OP
C***                                                                    OP
      GOTO 301                                                          OP
C***                                                                    OP
  311 CONTINUE                                                          OP
C***                                                                    OP
      IF(NSTEP.GT.60)GOTO 1                                             OP
      DO 342 I=1,6                                                      OP
  342 PREDCT(I)=DSQRT(SUM(I)/59)                                        OP
      PREDCT(2)=57.3*PREDCT(2)                                          OP
      PREDCT(3)=57.3*PREDCT(3)                                          OP
      PRINT 343,(PREDCT(I),I=1,6)                                       OP
  343 FORMAT(' ',F12.0,2F12.1,3F12.0)                                   OP
C***                                                                    OP
      GOTO 1                                                            OP
   92 CONTINUE                                                          OP
      STOP                                                              OP
      END                                                               OP
      BLOCK DATA                                                        OP
      IMPLICIT REAL*8(A-H,O-$)                                          OP
      COMMON/DAT0/S2LIAC,S2XYZR,TIMSOF,X00(11),S2WIND,S2WNDZ,S2WNDY     OP
     1,S2V,S2ALF,S2BET,S2H,S2DME,S2VOR,S2BDME,S2ZR,PERCNT,OMEGA,AGLOBE  OP
     4,OUTL1,OUTL2,S2QA,S2QB                                            OP
     2,EPS2,TLAM0,SMEW0,XST,YST,ZST,DIREQ,KDME(20),NDME1(20),NDME2(20)  OP
     3,KDME2(20),NXP,NRATE,NSTEP,IDGT,ISTDME,ISTVOR,SOF                 OP
      DIMENSION XST(7),YST(7),ZST(7),DIREQ(7)                           OP
```

```
      LOGICAL SOF                                                       C
      DATA SOF/ .FALSE. /,NXP/11/,S2LIAC/.4D0/,NRATE/20/,TIMSOF/1.0D0/  C
     1,X00/0.0D0,0.0D0,-116.0D0,125.0D0,0.0D0,12.0D0,5*0.0D0/           C
     2,S2V/6.25D0/,S2ALF/.000076D0/,S2WIND/.10D0/,S2WNDZ/.000001D0/     C
     3,S2BET/.000076D0/,S2H/25.0D0/,S2DME/40000.0D0/,S2VOR/.000004D0/   C
     4,NSTEP/60/,IDGT/3/,S2XYZR/25.0D0/,S2ZR/.10D0/                     C
     6,ISTDME/2/,ISTVOR/2/,S2BDME/.000025D0/,S2WNDY/.10D0/              C
     7,XST/.703D0,.6985D0,5*.706D0/                                     C
     8,YST/-1.297D0,-1.2985D0,5*-1.294D0/                               C
     9,ZST/7*0.0D0/                                                     C
     A,DIREQ/32.0D0,32.0D0,0.0D0,0.0D0,0.0D0,0.0D0,0.0D0/               C
     B,KDME/1,19*2500/,NDME1/1,2,3,1,4,15*2/,NDME2/2,3,1,4,16*3/        C
     C,OMEGA/.0000728D0/,AGLOBE/20940000.0D0/,EPS2/.0067D0/             C
     D,TLAM0/.700D0/,SMEW0/-1.300D0/                                    C
      DATA PERCNT/.000001D0/                                            C
     1,KDME2/1,19*2600/                                                 C
     2,OUTL1/20000.0D0/,OUTL2/20000.0D0/,S2QA/.81D0/,S2QB/.81D0/        C
      END                                                               C
```

```
C*                                                                      OE
C***STATE AND COVARIANCE MATRIX PROPAGATION BETWEEN MEASUREMENTS.       OE
C*                                                                      OE
      SUBROUTINE PROP27(TIMSOF,PERC1,OMEG1,AGLOB1,EPS1,S2W0Y            OE
     1,TLAM00,SMEW00,S2W0,S2WZ,X0,P0,XST,YST,ZST,DIREQ,S2ZR1,S2BDM      OE
     3,OUTL1T,OUTL2T,S2QAT,S2QBT                                        OE
     2,S2LIAC,S2XYZR,XOUT,P,HB,RES,IFLAG7,NRATE,NXP,ISTDME,ISTVOR,KSTEP)OE
      IMPLICIT REAL*8(A-H,O-$)                                          OE
      EQUIVALENCE (IC(202),NRATE1),(C(311),TIMSF)                       OE
      DIMENSION P0(11,11),X0(11),P01(11,11),P1(11,11),HB1(8,11),X01(11) OE
      EQUIVALENCE (C(467),S2LIA),(C(373),S2XYZ)                         OE
      EQUIVALENCE (IC(251),NXP1),(C(551),X01(1)),(C(593),P01(1,1))      OE
      EQUIVALENCE (C(993),HB1(1,1)),(C(793),P1(1,1))                    OE
      DIMENSION HB(6,11),XOUT(11),P(11,11),RES(6),Z(11),ZCAL(8)         OE
      EQUIVALENCE (C(469),XE),(C(471),YE),(C(473),ZE)                   OE
      EQUIVALENCE (C(481),USPEED),(C(483),VSPEED),(C(485),WSPEED)       OE
      EQUIVALENCE (C(571),Z(1)),(C(1235),ZCAL(1))                       OE
      DIMENSION XST(7),YST(7),ZST(7),DIREQ(7),XST1(7),YST1(7),ZST1(7)   OE
     1,DIREQ1(7)                                                        OE
      EQUIVALENCE (C(1257),XST1(1)),(C(1271),YST1(1))                   OE
      EQUIVALENCE (C(1299),DIREQ1(1)),(C(1285),ZST1(1))                 OE
      EQUIVALENCE (IC(252),ISTDM1),(IC(253),ISTVO1)                     OE
      EQUIVALENCE (IC(259),KSTEP1)                                      OE
      EQUIVALENCE (C(505),OMEGA),(C(507),AGLOBE),(C(509),EPS2)          OE
      EQUIVALENCE (C(511),TLAM0),(C(513),SMEW0)                         OE
      EQUIVALENCE (C(470),S2WNDZ)                                       OE
C***                                                                    OE
      EQUIVALENCE (C(482),WX),(C(484),WY),(C(486),WZ)                   OE
      EQUIVALENCE (C(468),S2WIND)                                       OE
      COMMON/COM/C(2000)                                                OE
      COMMON/INCOM/IC(500)                                              OE
C***                                                                    OP
      EQUIVALENCE (C(312),PERCNT),(C(381),S2ZR),(C(382),S2BDME)         OP
     1,(C(494),BDME1),(C(498),BDME2),(C(474),S2WNDY)                    OP
     2,(IC(261),IFLAG),(C(502),OUTL1),(C(504),OUTL2)                    OP
     3,(C(506),S2QA),(C(508),S2QB)                                      OP
      OUTL1=OUTL1T                                                      OP
      OUTL2=OUTL2T                                                      OP
      S2QA=S2QAT                                                        OP
      S2QB=S2QBT                                                        OP
      IFLAG=IFLAG7                                                      OP
      S2WNDY=S2W0Y                                                      OP
      S2ZR=S2ZR1                                                        OP
      S2BDME=S2BDM                                                      OP
      PERCNT=PERC1                                                      OP
C***                                                                    OP
      OMEGA=OMEG1                                                       OP
      AGLOBE=AGLOB1                                                     OP
      EPS2=EPS1                                                         OP
      TLAM0=TLAM00                                                      OP
      SMEW0=SMEW00                                                      OP
      KSTEP1=KSTEP                                                      OP
      NRATE1=NRATE                                                      OP
      TIMSF=TIMSOF                                                      OP
      S2LIA=S2LIAC                                                      OP
```

```
      S2XYZ=S2XYZR
      S2WIND=S2W0
      S2WNDZ=S2WZ
      NXP1=NXP
      DO 61 I=1,NXP1
   61 X01(I)=X0(I)
      DO 62 I=1,NXP1
      DO 62 J=1,NXP1
      P01(I,J)=P0(I,J)
   62 CONTINUE
      DO 64 I=1,7
      XST1(I)=XST(I)
      YST1(I)=YST(I)
      ZST1(I)=ZST(I)
   64 DIREQ1(I)=DIREQ(I)
      ISTDM1=ISTDME
      ISTVO1=ISTVOR
C
      CALL MYINIT
      CALL MYRUN
C***
      DO 101 I=1,NXP1
      DO 102 J=1,NXP1
      IF(I.LT.J)GOTO 101
  102 P1(J,I)=P1(I,J)
  101 CONTINUE
      XOUT(1)=XE
      XOUT(2)=YE
      XOUT(3)=ZE
      XOUT(4)=USPEED
      XOUT(5)=VSPEED
      XOUT(6)=WSPEED
      XOUT(7)=WX
      XOUT(8)=WY
      XOUT(9)=WZ
C*
      XOUT(10)=BDME1
      XOUT(11)=BDME2
C***K-TH VECTOR Z TRANSFERRED FROM INIT AND VECTOR ZCAL--FROM OUTPT
      DO 111 I=1,6
  111 RES(I)=Z(I+3)-ZCAL(I)
C*
      RES(5)=RES(5)-BDME1
      RES(6)=RES(6)-BDME2
C***
      DO 52 I=1,NXP1
      DO 52 J=1,NXP1
   52 P(I,J)=P1(I,J)
      DO 63 I=1,6
      DO 63 J=1,NXP1
   63 HB(I,J)=HB1(I,J)
C
      RETURN
      END
      SUBROUTINE MYINIT
```

```
      IMPLICIT REAL*8(A-H,O-$)                                          OP
      CALL INIT                                                         OP
      CALL DYNAMI                                                       OP
      RETURN                                                            OP
      END                                                               OP
      SUBROUTINE MYRUN                                                  OP
      IMPLICIT REAL*8(A-H,O-$)                                          OP
      COMMON/COM/C(2000)                                                OP
      COMMON/INCOM/IC(500)                                              OP
      EQUIVALENCE (C(305),TIME),(IC(207),NSTEP)                         OP
      EQUIVALENCE (IC(241),J1),(C(311),TIMSF)                           OP
C                                                                       OP
  242 CONTINUE                                                          OP
      IF(TIME.LT.TIMSF)GOTO 82                                          OP
      CALL OUTPT                                                        OP
      GOTO 100                                                          OP
C                                                                       OP
   82 CONTINUE                                                          OP
C                                                                       OP
C***R.K. LOOP                                                           OP
C                                                                       OP
      DO 246 J=1,4                                                      OP
      J1=J                                                              OP
      CALL DYNAM                                                        OP
C                                                                       OP
      CALL RKG                                                          OP
  246 CONTINUE                                                          OP
C                                                                       OP
C                                                                       OP
      NSTEP=NSTEP+1                                                     OP
      GOTO 242                                                          OP
  100 CONTINUE                                                          OP
      RETURN                                                            OP
      END                                                               OP
      SUBROUTINE INIT                                                   OP
      IMPLICIT REAL*8(A-H,O-$)                                          OP
      REAL*4 Z1(11),XA1(6)                                              OP
      DIMENSION IPL(100),IPD(100)                                       OP
      COMMON/COM/C(2000)                                                OP
      COMMON/INCOM/IC(500)                                              OP
      COMMON/RK/ARK(4),BRK(4),CRK(4),QRK(100)                           OP
C                                                                       OP
      EQUIVALENCE (IC(251),NXP1),(C(467),S2LIA),(C(373),S2XYZ)          OP
      COMMON/FQ/FB(11,11),QB(11,11)                                     OP
      EQUIVALENCE (C(993),HB1(1,1)),(C(571),Z(1))                       OP
      DIMENSION HB1(8,11),XA(6),Z(11)                                   OP
      EQUIVALENCE (IC(259),KSTEP1)                                      OP
C                                                                       OP
      EQUIVALENCE (IC(201),N)                                           OP
      EQUIVALENCE (IC(202),NRATE1),(C(305),TIME),(C(307),TIMED)         OP
      EQUIVALENCE (C(303),DT),(IC(207),NSTEP)                           OP
      EQUIVALENCE (C(309),CRAD),(C(301),GRAV1)                          OP
      EQUIVALENCE (C(493),ACCX),(C(495),ACCY),(C(497),ACCZ)             OP
      EQUIVALENCE (C(313),WP),(C(315),WQ),(C(317),WR)                   OP
      EQUIVALENCE (C(329),PHI),(C(327),TET),(C(325),PSI)                OP
```

```
      EQUIVALENCE (C(351),CEB11),(C(353),CEB12),(C(355),CEB13)
      EQUIVALENCE (C(357),CEB21),(C(359),CEB22),(C(361),CEB23)
      EQUIVALENCE (C(363),CEB31),(C(365),CEB32),(C(367),CEB33)
      EQUIVALENCE (IC(1),IPL(1)),(IC(101),IPD(1))
      EQUIVALENCE (C(468),S2WIND),(C(470),S2WNDZ)
     1,(C(381),S2ZR),(C(382),S2BDME),(C(474),S2WNDY)
     2,(IC(261),IFLAG),(C(502),OUTL1),(C(504),OUTL2)
     3,(C(506),S2QA),(C(508),S2QB)
C
      GRAV1=32.17D0
C
      ARK(1)=.5D0
      ARK(2)=1.0D0-1.0D0/DSQRT(2.0D0)
      ARK(3)=1.0D0+1.0D0/DSQRT(2.0D0)
      ARK(4)=1.0D0/6.0D0
      BRK(1)=2.0D0
      BRK(2)=1.0D0
      BRK(3)=1.0D0
      BRK(4)=2.0D0
      CRK(1)=ARK(1)
      CRK(2)=ARK(2)
      CRK(3)=ARK(3)
      CRK(4)=ARK(1)
      DO 229 I=1,100
  229 QRK(I)=0.0D0
C
      PI=4.0D0*DATAN(1.0D0)
      CRAD=180.0D0/PI
C
      IPL(1)=305
      IPD(1)=307
      N=1
      TIME=0.0D0
      TIMED=1.0D0
      NSTEP=0
      NRAT=NRATE1
      DT=1.0D0/DFLOAT(NRAT)
C***
C
      DO 306 I=1,NXP1
      DO 307 J=1,NXP1
  307 FB(I,J)=0.0D0
  306 CONTINUE
      DO 308 I=1,8
      DO 309 J=1,NXP1
  309 HB1(I,J)=0.0D0
  308 CONTINUE
      HB1(4,3)=-1.0D0
C*
      HB1(5,10)=1.0D0
      HB1(6,11)=1.0D0
      DO 311 I=1,NXP1
      DO 312 J=1,NXP1
  312 QB(I,J)=0.0D0
  311 CONTINUE
```

```
      QB(4,4)=S2LIA                                                    OP
      QB(5,5)=S2QA                                                     OP
      QB(6,6)=S2QB                                                     OP
      DO 314 I=1,2                                                     OP
  314 QB(I,I)=S2XYZ                                                    OP
      QB(3,3)=S2ZR                                                     OP
      QB(7,7)=S2WIND                                                   OP
      QB(8,8)=S2WNDY                                                   OP
      QB(9,9)=S2WNDZ                                                   OP
C*                                                                     OP
      QB(10,10)=S2BDME                                                 OP
      QB(11,11)=S2BDME                                                 OP
C***                                                                   OP
C***READ IN SMOOTHED VECTOR X OF MODEL A AND VECTOR Z AT K-TH TIME     OP
C***POINT.Z COSTITUTES OF INPUT(ACCEL MEASUREMENTS) AND MEASUREMENT    OP
C***MATRICES.FIRST NEEDED IN DYNAM AND SECOND--IN MAIN.                OP
C                                                                      OP
      IF(KSTEP1.EQ.2)GOTO 319                                          OP
      READ(10) (XA1(I),I=1,6)                                          OP
  319 CONTINUE                                                         OP
      READ(9) (Z1(I),I=1,11)                                           OP
      Z(5)=Z1(5)/CRAD                                                  OP
      Z(6)=Z1(6)/CRAD                                                  OP
      Z(10)=Z1(10)/CRAD                                                OP
      Z(11)=Z1(11)/CRAD                                                OP
      Z(4)=Z1(4)                                                       OP
      Z(7)=Z1(7)                                                       OP
      Z(8)=Z1(8)                                                       OP
      Z(9)=Z1(9)                                                       OP
C***                                                                   OP
      WP=XA1(1)                                                        OP
      WQ=XA1(2)                                                        OP
      WR=XA1(3)                                                        OP
      PHI=XA1(4)                                                       OP
      TET=XA1(5)                                                       OP
      PSI=XA1(6)                                                       OP
      CALL ROTAT                                                       OP
      ACCX=Z1(1)                                                       OP
      ACCY=Z1(2)                                                       OP
      ACCZ=Z1(3)                                                       OP
C*                                                                     OP
C* IFLAG=5 FOR FIRST STEP                                              OP
      IF(IFLAG.NE.5)GOTO 837                                           OP
      OOR1=Z(8)                                                        OP
      ONR1=Z(8)                                                        OP
      OOR2=Z(9)                                                        OP
      ONR2=Z(9)                                                        OP
      GOTO 838                                                         OP
  837 CONTINUE                                                         OP
      IF(DABS(Z(8)-ONR1).LT.OUTL1)GOTO 839                             OP
      Z(8)=ONR1+(ONR1-OOR1)                                            OP
  839 CONTINUE                                                         OP
      OOR1=ONR1                                                        OP
      ONR1=Z(8)                                                        OP
      IF(DABS(Z(9)-ONR2).LT.OUTL2)GOTO 840                             OP
```

```
      Z(9)=ONR2+(ONR2-OOR2)
  840 CONTINUE
      OOR2=ONR2
      ONR2=Z(9)
  838 CONTINUE
C*
      RETURN
      END
      SUBROUTINE DYNAMI
      IMPLICIT REAL*8(A-H,O-$)
      DIMENSION IPL(100),IPD(100)
      COMMON/COM/C(2000)
      COMMON/INCOM/IC(500)
C***
      DIMENSION X01(11),P01(11,11),P1(11,11)
      EQUIVALENCE (C(337),CSF),(C(339),SNF),(C(341),CST),(C(343),SNT)
     1,(C(505),OMEGA),(C(507),AGLOBE),(C(509),EPS2)
     2,(C(511),TLAM0)
     3,(C(351),CEB11),(C(352),CEB12),(C(353),CEB13)
     4,(C(354),CEB21),(C(355),CEB22),(C(356),CEB23)
     5,(C(357),CEB31),(C(358),CEB32),(C(359),CEB33)
     6,(C(494),BDME1),(C(498),BDME2),(C(312),PERCNT),(C(311),TIMSF)
     7,(C(313),WP),(C(315),WQ),(C(317),WR)
      COMMON/FQ/FB(11,11),QB(11,11)
      DIMENSION B60(11,11),FKDT(11,11),SUME(11,11),SUME1(11,11)
     1,TMAT(11,11),TMATT(11,11),PTMATT(11,11),TMPTMT(11,11)
      EQUIVALENCE (IC(251),NXP1),(C(551),X01(1)),(C(593),P01(1,1))
      EQUIVALENCE (C(793),P1(1,1))
C***
      EQUIVALENCE (IC(201),N)
      EQUIVALENCE (C(303),DT)
      EQUIVALENCE (C(327),TET),(C(325),PSI),(C(329),PHI)
      EQUIVALENCE (C(469),XE),(C(471),YE),(C(473),ZE)
      EQUIVALENCE (C(481),USPEED),(C(485),WSPEED),(C(483),VSPEED)
      EQUIVALENCE (IC(1),IPL(1)),(IC(101),IPD(1))
      EQUIVALENCE (C(482),WX),(C(484),WY),(C(486),WZ)
C
      N=N+1
      IPL(N)=469
      IPD(N)=475
      N=N+1
      IPL(N)=471
      IPD(N)=477
      N=N+1
      IPL(N)=473
      IPD(N)=479
      N=N+1
      IPL(N)=481
      IPD(N)=487
      N=N+1
      IPL(N)=483
      IPD(N)=489
      N=N+1
      IPL(N)=485
      IPD(N)=491
```

```
C***                                                                    OP
      N=N+1                                                             OP
       IPL(N)=482                                                       OP
       IPD(N)=488                                                       OP
      N=N+1                                                             OP
       IPL(N)=484                                                       OP
       IPD(N)=490                                                       OP
      N=N+1                                                             OP
       IPL(N)=486                                                       OP
       IPD(N)=492                                                       OP
C*                                                                      OP
      N=N+1                                                             OP
       IPL(N)=494                                                       OP
       IPD(N)=496                                                       OP
      N=N+1                                                             OP
       IPL(N)=498                                                       OP
       IPD(N)=500                                                       OP
C                                                                       OP
      XE=X01(1)                                                         OP
      YE=X01(2)                                                         OP
      ZE=X01(3)                                                         OP
C                                                                       OP
      USPEED=X01(4)                                                     OP
      VSPEED=X01(5)                                                     OP
      WSPEED=X01(6)                                                     OP
C***                                                                    OP
      WX=X01(7)                                                         OP
      WY=X01(8)                                                         OP
      WZ=X01(9)                                                         OP
C*                                                                      OP
      BDME1=X01(10)                                                     OP
      BDME2=X01(11)                                                     OP
C***                                                                    OP
      DO 201 I=1,NXP1                                                   OP
  201 P1(I,1)=P01(I,1)                                                  OP
      DO 202 I=2,NXP1                                                   OP
  202 P1(I,2)=P01(I,2)                                                  OP
      DO 203 I=3,NXP1                                                   OP
  203 P1(I,3)=P01(I,3)                                                  OP
      DO 204 I=4,NXP1                                                   OP
  204 P1(I,4)=P01(I,4)                                                  OP
      DO 205 I=5,NXP1                                                   OP
  205 P1(I,5)=P01(I,5)                                                  OP
      DO 206 I=6,NXP1                                                   OP
  206 P1(I,6)=P01(I,6)                                                  OP
      DO 207 I=7,NXP1                                                   OP
  207 P1(I,7)=P01(I,7)                                                  OP
      DO 208 I=8,NXP1                                                   OP
  208 P1(I,8)=P01(I,8)                                                  OP
      DO 209 I=9,NXP1                                                   OP
  209 P1(I,9)=P01(I,9)                                                  OP
      DO 210 I=10,NXP1                                                  OP
  210 P1(I,10)=P01(I,10)                                                OP
      P1(11,11)=P01(11,11)                                              OP
C***                                                                    OP
```

```
      DO 101 I=1,NXP1                                                  (
      DO 102 J=1,NXP1                                                  (
      IF(I.LT.J)GOTO 101                                               (
  102 P1(J,I)=P1(I,J)                                                  (
  101 CONTINUE                                                         (
C***                                                                   (
      TLAM=TLAM0+XE/AGLOBE                                             (
      COST=DCOS(TLAM)                                                  (
      SINT=DSIN(TLAM)                                                  (
      TANT=SINT/COST                                                   (
      SIN2T=2*SINT*COST                                                (
      COS2T=COST*COST-SINT*SINT                                        (
      C1111=1.0D0-ZE/AGLOBE-.5D0*EPS2*COS2T                            (
      C112=1/C1111                                                     (
C                                                                      (
C                                                                      (
      C141=C112*(ZE/AGLOBE+.5*EPS2*COS2T)                              (
      C111=(CEB11*USPEED+CEB21*VSPEED+CEB31*WSPEED+WX)/AGLOBE          (
      C211=(CEB12*USPEED+CEB22*VSPEED+CEB32*WSPEED+WY)/AGLOBE          (
      C241=-C112*YE*TANT/AGLOBE                                        (
      C341=C112*EPS2*SIN2T                                             (
      C56=OMEGA*(CEB11*COST-CEB13*SINT)                                (
      C64=OMEGA*(CEB21*COST-CEB23*SINT)                                (
      C45=OMEGA*(CEB31*COST-CEB33*SINT)                                (
C***                                                                   (
      C413=OMEGA*(CEB11*SINT+CEB13*COST)                               (
      C412=OMEGA*(CEB21*SINT+CEB23*COST)                               (
      C411=OMEGA*(CEB31*SINT+CEB33*COST)                               (
      CENT1=-OMEGA**2*AGLOBE*C1111*.5*SIN2T                            (
      CENT2=-OMEGA**2*AGLOBE*C1111*COST**2                             (
      C47=2*(+WR*CEB21-WQ*CEB31)+OMEGA*CEB12*SINT                      (
      C48=2*(+WR*CEB22-WQ*CEB32)-C413                                  (
      C49=2*(+WR*CEB23-WQ*CEB33)-OMEGA*CEB12*COST                      (
      C57=2*(-WR*CEB11+WP*CEB31)+OMEGA*CEB22*SINT                      (
      C58=2*(-WR*CEB12+WP*CEB32)-C412                                  (
      C59=2*(-WR*CEB13+WP*CEB33)-OMEGA*CEB22*COST                      (
      C67=2*(+WQ*CEB11-WP*CEB21)+OMEGA*CEB32*SINT                      (
      C68=2*(+WQ*CEB12-WP*CEB22)-C411                                  (
      C69=2*(+WQ*CEB13-WP*CEB23)-OMEGA*CEB32*COST                      (
C                                                                      (
C***                                                                   (
      C1122=C112*C112                                                  (
      C2112=C211*C1122                                                 (
      C13=C111*C1122                                                   (
      C11=-EPS2*SIN2T*C13                                              (
      C31=C111*C112*EPS2*(2*COS2T-C112*EPS2*SIN2T*SIN2T)               (
      C33=C13*EPS2*SIN2T                                               (
      C21=-EPS2*SIN2T*C2112+C13*(-C1111+.5D0*EPS2*SIN2T*SIN2T)*YE/     (
     1 AGLOBE/COST/COST                                                (
      C22=-C111*C112*TANT                                              (
      C23=C2112-C13*TANT*YE/AGLOBE                                     (
      C14=C141*CEB11                                                   (
      C15=C141*CEB21                                                   (
      C16=C141*CEB31                                                   (
      C24=C241*CEB11+C141*CEB12                                        (
```

```
      C25=C241*CEB21+C141*CEB22                                         OP
      C26=C241*CEB31+C141*CEB32                                         OP
      C34=C341*CEB11                                                    OP
      C35=C341*CEB21                                                    OP
      C36=C341*CEB31                                                    OP
      C17=C141                                                          OP
      C27=C241                                                          OP
      C28=C141                                                          OP
      C37=C341                                                          OP
      C411=OMEGA*(CEB31*SINT+CEB33*COST)                                OP
      C412=OMEGA*(CEB21*SINT+CEB23*COST)                                OP
      C413=OMEGA*(CEB11*SINT+CEB13*COST)                                OP
      C433=OMEGA*COST                                                   OP
      C43=C433*C413                                                     OP
      C53=C433*C412                                                     OP
      C63=C433*C411                                                     OP
      COST1=COST*OMEGA/AGLOBE                                           OP
      SINT1=SINT*OMEGA/AGLOBE                                           OP
      C4111=(C1111*COS2T+.5D0*EPS2*SIN2T*SIN2T)*OMEGA*OMEGA             OP
      C4112=(C1111*SIN2T-     EPS2*SIN2T*COST*COST)*OMEGA*OMEGA         OP
      C41=(WSPEED*C412-VSPEED*C411)/AGLOBE                              OP
     1-CEB11*C4111+CEB13*C4112+COST1*(WX*CEB12-WY*CEB11)+SINT1*(        OP
     2 WY*CEB13+WZ*CEB12)                                               OP
      C51=(USPEED*C411-WSPEED*C413)/AGLOBE                              OP
     1-CEB21*C4111+CEB23*C4112+COST1*(WX*CEB22-WY*CEB21)+SINT1*(        OP
     2 WY*CEB23+WZ*CEB22)                                               OP
      C61=(VSPEED*C413-USPEED*C412)/AGLOBE                              OP
     1-CEB31*C4111+CEB33*C4112+COST1*(WX*CEB32-WY*CEB31)+SINT1*(        OP
     2 WY*CEB33+WZ*CEB32)                                               OP
      C65=-C56                                                          OP
      C46=-C64                                                          OP
      C54=-C45                                                          OP
      FB(1,1)=C11                                                       OP
      FB(2,1)=C21                                                       OP
      FB(3,1)=C31                                                       OP
      FB(4,1)=C41                                                       OP
      FB(5,1)=C51                                                       OP
      FB(6,1)=C61                                                       OP
      FB(2,2)=C22                                                       OP
      FB(1,3)=C13                                                       OP
      FB(2,3)=C23                                                       OP
      FB(3,3)=C33                                                       OP
      FB(4,3)=C43                                                       OP
      FB(5,3)=C53                                                       OP
      FB(6,3)=C63                                                       OP
      FB(1,4)=CEB11+C14                                                 OP
      FB(2,4)=CEB12+C24                                                 OP
      FB(3,4)=+CEB13+C34                                                OP
      FB(1,5)=CEB21+C15                                                 OP
      FB(2,5)=CEB22+C25                                                 OP
      FB(3,5)=+CEB23+C35                                                OP
      FB(1,6)=CEB31+C16                                                 OP
      FB(2,6)=CEB32+C26                                                 OP
      FB(3,6)=+CEB33+C36                                                OP
      FB(5,4)=-WR+C54                                                   OP
```

```
      FB(6,4)=WQ+C64
      FB(4,5)=WR+C45
      FB(6,5)=-WP+C65
      FB(4,6)=-WQ+C46
      FB(5,6)=WP+C56
      FB(1,7)=1.0D0+C17
      FB(2,8)=1.0D0+C141
      FB(3,9)=1.0D0
      FB(2,7)=C27
      FB(3,7)=C37
      FB(4,7)=C47
      FB(4,8)=C48
      FB(4,9)=C49
      FB(5,7)=C57
      FB(5,8)=C58
      FB(5,9)=C59
      FB(6,7)=C67
      FB(6,8)=C68
      FB(6,9)=C69
C****
C
      CALL CSTM(FB,PERCNT,TIMSF,TMAT,B60,FKDT,SUME,SUME1,NXP1,NTERMS)
      DO 600 I=1,NXP1
      DO 600 J=1,NXP1
  600 TMATT(J,I)=TMAT(I,J)
      DO 610 I=1,NXP1
      DO 610 J=1,NXP1
  610 TMPTMT(I,J)=P1(I,J)+QB(I,J)
      CALL VMULFF(TMPTMT,TMATT ,NXP1,NXP1,NXP1,NXP1,NXP1,PTMATT,NXP1,I1)
      CALL VMULFF(TMAT   ,PTMATT,NXP1,NXP1,NXP1,NXP1,NXP1,P1    ,NXP1,I2)
C
      RETURN
      END
      SUBROUTINE DYNAM
      IMPLICIT REAL*8(A-H,O-$)
      COMMON/COM/C(2000)
      COMMON/INCOM/IC(500)
C***
      EQUIVALENCE (IC(251),NXP1)
      COMMON/FQ/FB(11,11),QB(11,11)
      EQUIVALENCE (C(494),BDME1),(C(496),DBDME1)
     1,(C(498),BDME2),(C(500),DBDME2)
      EQUIVALENCE (C(793),P1(1,1))
      EQUIVALENCE (C(401),DP11),(C(402),DP21),(C(403),DP31)
      EQUIVALENCE (C(404),DP41),(C(405),DP51),(C(406),DP61)
      EQUIVALENCE (C(407),DP71),(C(408),DP81),(C(409),DP91)
      EQUIVALENCE (C(410),DP22),(C(411),DP32),(C(412),DP42)
      EQUIVALENCE (C(413),DP52),(C(414),DP62),(C(415),DP72)
      EQUIVALENCE (C(416),DP82),(C(417),DP92)
      EQUIVALENCE (C(418),DP33),(C(419),DP43),(C(420),DP53)
      EQUIVALENCE (C(421),DP63),(C(422),DP73),(C(423),DP83)
      EQUIVALENCE (C(424),DP93)
      EQUIVALENCE (C(425),DP44),(C(426),DP54),(C(427),DP64)
      EQUIVALENCE (C(428),DP74),(C(429),DP84),(C(430),DP94)
      EQUIVALENCE (C(431),DP55),(C(432),DP65),(C(433),DP75)
```

```
      EQUIVALENCE (C(434),DP85),(C(435),DP95),(C(436),DP66)                OP
      EQUIVALENCE (C(437),DP76),(C(438),DP86),(C(439),DP96)                OP
      EQUIVALENCE (C(440),DP77),(C(441),DP87),(C(442),DP97)                OP
      EQUIVALENCE (C(443),DP88),(C(444),DP98),(C(445),DP99)                OP
      EQUIVALENCE (C(319),WPD),(C(321),WQD),(C(323),WRD)                   OP
      DIMENSION DPM(11,11),FP(11,11),P1(11,11)                             OP
C***                                                                       OP
      EQUIVALENCE (C(482),WX),(C(484),WY),(C(486),WZ)                      OP
      EQUIVALENCE (C(488),DWX),(C(490),DWY),(C(492),DWZ)                   OP
C                                                                          OP
      EQUIVALENCE (C(315),WQ),(C(327),TET),(C(333),DTET)                   OP
      EQUIVALENCE (C(499),VX),(C(503),VZ)                                  OP
      EQUIVALENCE (C(469),XE),(C(473),ZE),(C(475),XED),(C(479),ZED)        OP
      EQUIVALENCE (C(351),CEB11)                                           OP
      EQUIVALENCE (C(355),CEB13),(C(363),CEB31),(C(367),CEB33)             OP
      EQUIVALENCE (C(325),PSI),(C(329),PHI),(C(331),DPSI),(C(335),DPHI)    OP
      EQUIVALENCE (C(313),WP),(C(317),WR)                                  OP
      EQUIVALENCE (C(501),VY),(C(471),YE),(C(477),YED)                     OP
      EQUIVALENCE (C(337),CSF),(C(339),SNF),(C(341),CST),(C(343),SNT)      OP
      EQUIVALENCE (C(353),CEB12),(C(357),CEB21),(C(359),CEB22)             OP
      EQUIVALENCE (C(361),CEB23),(C(365),CEB32)                            OP
      EQUIVALENCE (C(493),ACCX),(C(495),ACCY),(C(497),ACCZ)                OP
      EQUIVALENCE (C(481),USPEED),(C(483),VSPEED),(C(485),WSPEED)          OP
      EQUIVALENCE (C(487),DUSPED),(C(489),DVSPED),(C(491),DWSPED)          OP
      EQUIVALENCE (C(301),GRAV1)                                           OP
      EQUIVALENCE (C(511),TLAM0)                                           OP
      EQUIVALENCE (C(505),OMEGA),(C(507),AGLOBE),(C(509),EPS2)             OP
C***                                                                       OP
C                                                                          OP
      CALL DBTOI(USPEED,VSPEED,WSPEED,CEB11,CEB12,CEB13                    OP
     1,CEB21,CEB22,CEB23,CEB31,CEB32,CEB33,VX,VY,VZ)                       OP
C***                                                                       OP
      DO 101 I=1,NXP1                                                      OP
      DO 102 J=1,NXP1                                                      OP
      IF(I.LT.J)GOTO 101                                                   OP
  102 P1(J,I)=P1(I,J)                                                      OP
  101 CONTINUE                                                             OP
      TLAM=TLAM0+XE/AGLOBE                                                 OP
      COST=DCOS(TLAM)                                                      OP
      SINT=DSIN(TLAM)                                                      OP
      TANT=SINT/COST                                                       OP
      SIN2T=2*SINT*COST                                                    OP
      COS2T=COST*COST-SINT*SINT                                            OP
      C1111=1.0D0-ZE/AGLOBE-.5D0*EPS2*COS2T                                OP
      C112=1/C1111                                                         OP
C                                                                          OP
C                                                                          OP
      C141=C112*(ZE/AGLOBE+.5*EPS2*COS2T)                                  OP
      C111=(CEB11*USPEED+CEB21*VSPEED+CEB31*WSPEED+WX)/AGLOBE              OP
      C211=(CEB12*USPEED+CEB22*VSPEED+CEB32*WSPEED+WY)/AGLOBE              OP
      C241=-C112*YE*TANT/AGLOBE                                            OP
      C341=C112*EPS2*SIN2T                                                 OP
      C56=OMEGA*(CEB11*COST-CEB13*SINT)                                    OP
      C64=OMEGA*(CEB21*COST-CEB23*SINT)                                    OP
      C45=OMEGA*(CEB31*COST-CEB33*SINT)                                    OP
```

```
      XED=VX+WX+C141*C111*AGLOBE
      ZED=+VZ+WZ+C341*C111*AGLOBE
      YED=VY+WY+C141*C211*AGLOBE+C241*C111*AGLOBE
C***
      C413=OMEGA*(CEB11*SINT+CEB13*COST)
      C412=OMEGA*(CEB21*SINT+CEB23*COST)
      C411=OMEGA*(CEB31*SINT+CEB33*COST)
      CENT1=-OMEGA**2*AGLOBE*C1111*.5*SIN2T
      CENT2=-OMEGA**2*AGLOBE*C1111*COST**2
      C47=2*(+WR*CEB21-WQ*CEB31)+OMEGA*CEB12*SINT
      C48=2*(+WR*CEB22-WQ*CEB32)-C413
      C49=2*(+WR*CEB23-WQ*CEB33)-OMEGA*CEB12*COST
      C57=2*(-WR*CEB11+WP*CEB31)+OMEGA*CEB22*SINT
      C58=2*(-WR*CEB12+WP*CEB32)-C412
      C59=2*(-WR*CEB13+WP*CEB33)-OMEGA*CEB22*COST
      C67=2*(+WQ*CEB11-WP*CEB21)+OMEGA*CEB32*SINT
      C68=2*(+WQ*CEB12-WP*CEB22)-C411
      C69=2*(+WQ*CEB13-WP*CEB23)-OMEGA*CEB32*COST
C
C***
      DUSPED=-WQ*WSPEED+WR*VSPEED     +ACCX*GRAV1
     1+C45*VSPEED-C64*WSPEED
     2+C47*WX+C48*WY+C49*WZ+CENT1*CEB11+CENT2*CEB13
C*
C*
      DVSPED=-WR*USPEED+WP*WSPEED+ACCY*GRAV1
     1-C45*USPEED+C56*WSPEED
     2+C57*WX+C58*WY+C59*WZ+CENT1*CEB21+CENT2*CEB23
      DWSPED=+WQ*USPEED-WP*VSPEED+ACCZ*GRAV1
     1+C64*USPEED-C56*VSPEED
     2+C67*WX+C68*WY+C69*WZ+CENT1*CEB31+CENT2*CEB33
C
      DWX=0.0D0
      DWY=0.0D0
      DWZ=0.0D0
C*
      DBDME1=0.0D0
      DBDME2=0.0D0
C***
C
      RETURN
      END
      SUBROUTINE OUTPT
      IMPLICIT REAL*8(A-H,O-$)
      COMMON/COM/C(2000)
      COMMON/INCOM/IC(500)
      DIMENSION RDME(7),VOR(7)
C***
      DIMENSION XST1(7),YST1(7),ZST1(7),DIREQ1(7)
      EQUIVALENCE (C(1257),XST1(1)),(C(1271),YST1(1)),(C(1285),ZST1(1))
      EQUIVALENCE (C(1299),DIREQ1(1)),(IC(252),ISTDM1),(IC(253),ISTVO1)
      EQUIVALENCE (C(993),HB1(1,1))
      EQUIVALENCE (C(1235),ZCAL(1))
      DIMENSION ZCAL(8),HB1(8,11)
C
```

```
      EQUIVALENCE (C(309),CRAD)                                          OP
      EQUIVALENCE (C(473),ZE)                                            OP
      EQUIVALENCE (C(305),TIME)                                          OP
      EQUIVALENCE (C(315),WQ),(C(499),VX),(C(503),VZ),(C(469),XE)        OP
      EQUIVALENCE (C(327),TET)                                           OP
      EQUIVALENCE (C(325),PSI),(C(329),PHI)                              OP
      EQUIVALENCE (C(313),WP),(C(317),WR),(C(501),VY),(C(471),YE)        OP
      EQUIVALENCE (C(493),ACCX),(C(495),ACCY),(C(497),ACCZ)              OP
      EQUIVALENCE (C(481),USPEED),(C(483),VSPEED),(C(485),WSPEED)        OP
      EQUIVALENCE (C(507),AGLOBE),(C(509),EPS2)                          OP
      EQUIVALENCE (C(511),TLAM0),(C(513),SMEW0)                          OP
      DIMENSION XDME(7),YDME(7),ZDME(7)                                  OP
C***                                                                     OP
      TLAM=TLAM0+XE/AGLOBE                                               OP
      COST=DCOS(TLAM)                                                    OP
      SINT=DSIN(TLAM)                                                    OP
      TANT=SINT/COST                                                     OP
      SMEW=SMEW0+YE/AGLOBE/COST                                          OP
      SIN2T=2*SINT*COST                                                  OP
      COS2T=COST*COST-SINT*SINT                                          OP
      C1111=1.0D0-.5D0*EPS2*COS2T-ZE/AGLOBE                              OP
      AC1111=AGLOBE*C1111                                                OP
      COSS=DCOS(SMEW)                                                    OP
      SINS=DSIN(SMEW)                                                    OP
      RX1=EPS2*SIN2T*COST*COSS-C1111*SINT*COSS-C1111*TANT*SINS*YE/AGLOBEOP
      RX2=EPS2*SIN2T*COST*SINS-C1111*SINT*SINS+C1111*TANT*COSS*YE/AGLOBEOP
      RX3=EPS2*SIN2T*SINT+C1111*COST                                     OP
C                                                                        OP
C***VECTORS X OF MODEL A AND Z(K-TH TIME POINT) OF MODEL B(WITHOUT       OP
C***ACCEL) TRANSFERRED FROM INIT                                         OP
C                                                                        OP
      VAIR2=USPEED**2+VSPEED**2+WSPEED**2                                OP
      VAIR=DSQRT(VAIR2)                                                  OP
      VRP=VSPEED                                                         OP
      USPD=USPEED                                                        OP
      BETA=DATAN2(VRP,USPD)                                              OP
      WQR=WSPEED                                                         OP
      ALPHA=DATAN2(WQR,USPD)                                             OP
      DO 301 I=1,ISTDM1                                                  OP
      XDME(I)=AC1111*COST*COSS-DCOS(XST1(I))*DCOS(YST1(I))*              OP
     1 (-ZST1(I)+AGLOBE*(1.0D0-.5D0*EPS2*DCOS(2*XST1(I))))               OP
      YDME(I)=AC1111*COST*SINS-DCOS(XST1(I))*DSIN(YST1(I))*              OP
     1 (-ZST1(I)+AGLOBE*(1.0D0-.5D0*EPS2*DCOS(2*XST1(I))))               OP
      ZDME(I)=AC1111*SINT      -DSIN(XST1(I))*                           OP
     1 (-ZST1(I)+AGLOBE*(1.0D0-.5D0*EPS2*DCOS(2*XST1(I))))               OP
C***XST,YST ARE LATITUDE AND LONGITUDE                                   OP
  301 RDME(I)=DSQRT(XDME(I)**2+YDME(I)**2+ZDME(I)**2)                    OP
C                                                                        OP
C*301 RDME(I)=DSQRT((XE-XST1(I))**2+(YE-YST1(I))**2+(ZE-ZST1(I))**2)     OP
C                                                                        OP
      DO 302 I=1,ISTVO1                                                  OP
  302 VOR(I)=1.                                                          OP
C***                                                                     OP
      ZCAL(1)=VAIR                                                       OP
      ZCAL(2)=ALPHA                                                      OP
```

```
      ZCAL(3)=BETA
      ZCAL(4)=-ZE
      ZCAL(5)=RDME(1)
      ZCAL(6)=RDME(2)
      ZCAL(7)=VOR(1)
      ZCAL(8)=VOR(2)
C
      HB1(5,1)=(RX1*XDME(1)+RX2*YDME(1)+RX3*ZDME(1))/RDME(1)
      HB1(6,1)=(RX1*XDME(2)+RX2*YDME(2)+RX3*ZDME(2))/RDME(2)
      HB1(5,2)=(-C1111*SINS*XDME(1)+C1111*COSS*YDME(1))/RDME(1)
      HB1(6,2)=(-C1111*SINS*XDME(2)+C1111*COSS*YDME(2))/RDME(2)
      HB1(5,3)=(-COST*COSS*XDME(1)-COST*SINS*YDME(1)-SINT*ZDME(1))
     1/RDME(1)
      HB1(6,3)=(-COST*COSS*XDME(2)-COST*SINS*YDME(2)-SINT*ZDME(2))
     1/RDME(2)
      HB1(7,1)=-(YE-YST1(1))/(RDME(1)**2-(ZE-ZST1(1))**2)
      HB1(8,1)=-(YE-YST1(2))/(RDME(2)**2-(ZE-ZST1(2))**2)
      HB1(7,2)=(XE-XST1(1))/(RDME(1)**2-(ZE-ZST1(1))**2)
      HB1(8,2)=(XE-XST1(2))/(RDME(2)**2-(ZE-ZST1(2))**2)
      HB1(1,4)=USPEED/VAIR
      HB1(2,4)=-WSPEED/(VAIR2-VSPEED**2)
      HB1(3,4)=-VSPEED/(VAIR2-WSPEED**2)
      HB1(1,5)=VSPEED/VAIR
      HB1(3,5)=USPEED/(VAIR2-WSPEED**2)
      HB1(1,6)=WSPEED/VAIR
      HB1(2,6)=USPEED/(VAIR2-VSPEED**2)
C
      RETURN
      END
      FUNCTION SATF(X11,XM11)
      IMPLICIT REAL*8(A-H,O-$)
      SATF=DSIGN(DMIN1(DABS(X11),XM11),X11)
      RETURN
      END
      SUBROUTINE ROTAT
      IMPLICIT REAL*8(A-H,O-$)
      COMMON/COM/C(2000)
      EQUIVALENCE (C(327),TET),(C(351),CEB11),(C(355),CEB13)
      EQUIVALENCE (C(363),CEB31),(C(367),CEB33)
      EQUIVALENCE (C(341),CST),(C(343),SNT)
      EQUIVALENCE (C(325),PSI),(C(329),PHI),(C(353),CEB12)
      EQUIVALENCE (C(357),CEB21),(C(359),CEB22),(C(361),CEB23)
      EQUIVALENCE (C(365),CEB32),(C(345),CSP),(C(347),SNP)
      EQUIVALENCE (C(337),CSF),(C(339),SNF)
C
      SNT=DSIN(TET)
      CST=DCOS(TET)
      SNP=DSIN(PSI)
      CSP=DCOS(PSI)
      SNF=DSIN(PHI)
      CSF=DCOS(PHI)
C
      CEB11=CST*CSP
      CEB13=-SNT
      CEB31=+SNT*CSF*CSP+SNF*SNP
```

```
      CEB33=CST*CSF                                                     OP
      CEB12=CST*SNP                                                     OP
      CEB21=SNF*SNT*CSP-CSF*SNP                                         OP
      CEB22=SNF*SNT*SNP+CSF*CSP                                         OP
      CEB23=SNF*CST                                                     OP
      CEB32=CSF*SNT*SNP-SNF*CSP                                         OP
      RETURN                                                            OP
      END                                                               OP
      SUBROUTINE DITOB(XI,YI,ZI,A11,A12,A13,A21,A22,A23,A31,A32,A33,    OP
     1XO,YO,ZO)                                                         OP
      IMPLICIT REAL*8(A-H,O-$)                                          OP
      XO=A11*XI+A13*ZI+A12*YI                                           OP
      ZO=A31*XI+A33*ZI+A32*YI                                           OP
      YO=A21*XI+A22*YI+A23*ZI                                           OP
      RETURN                                                            OP
      ENTRY DBTOI(XI,YI,ZI,A11,A12,A13,A21,A22,A23,A31,A32,A33,         OP
     1XO,YO,ZO)                                                         OP
      XO=A11*XI+A31*ZI+A21*YI                                           OP
      ZO=A13*XI+A33*ZI+A23*YI                                           OP
      YO=A12*XI+A22*YI+A32*ZI                                           OP
      RETURN                                                            OP
      END                                                               OP
      SUBROUTINE RKG                                                    OP
      IMPLICIT REAL*8(A-H,O-$)                                          OP
      DIMENSION IPL(100),IPD(100)                                       OP
      COMMON/COM/C(2000)                                                OP
      COMMON/RK/ARK(4),BRK(4),CRK(4),QRK(100)                           OP
      COMMON/INCOM/IC(500)                                              OP
C                                                                       OP
      EQUIVALENCE (IC(201),N)                                           OP
      EQUIVALENCE (C(303),H),(IC(241),J)                                OP
      EQUIVALENCE (IC(1),IPL(1)),(IC(101),IPD(1))                       OP
C                                                                       OP
      DO 100 I=1,N                                                      OP
      IL=IPL(I)                                                         OP
      ID=IPD(I)                                                         OP
      X1=C(ID)*H                                                        OP
      X2=(X1-BRK(J)*QRK(I))*ARK(J)                                      OP
      C(IL)=C(IL)+X2                                                    OP
100   QRK(I)=QRK(I)+3.0D0*X2-CRK(J)*X1                                  OP
C                                                                       OP
      RETURN                                                            OP
      END                                                               OP
```

```
C*                                                                      0
C*OPTIMAL SMOOTHING PROGRAM                                             0
C*                                                                      0
      IMPLICIT REAL*8(A-H,O-$)                                          0
      REAL*4 XS1(11),PS1(9,9),XAS(6,1)                                  0
      COMMON/DAT0/PERCNT,DT,TLAM0,OMEGA,AGLOBE,EPS2,IDGT,NSTEP,NXP,SOF  0
      LOGICAL GO,SOF                                                    0
      NAMELIST/INP/FILE                                                 0
      INTEGER FILE(2)                                                   0
      NAMELIST/OK/GO                                                    0
      NAMELIST/DAT/SOF,NSTEP,NXP,PERCNT,DT,IDGT,TLAM0                   0
     1,OMEGA,AGLOBE,EPS2                                                0
C***                                                                    0
      DEFINE FILE 17( 150,368,L,KSTEPG)                                 0
      DEFINE FILE 12( 150,2112,L       ,KSTEPA)                         0
      DIMENSION XPK12(11),XMK12(11),PPK12(11,11),PMK12(11,11)           0
C*                                                                      0
      DIMENSION XPK1(6),XMK1(6),XPK(6),XMK(6)                           0
     1,PPK1(6,6),PMK1(6,6),PPK(6,6),PMK(6,6)                            0
     2,FK(6,6),TMAT(6,6),TMATT(6,6),PTMATT(6,6)                         0
     3,PINV(6,6),WKAREA(60),AK(6,6),AKT(6,6)                            0
     4,DELX(6,1),DELP(6,6),DELXES(6,1),XS(6)                            0
     5,AKDELP(6,6),ADPAT(6,6),PS(6,6)                                   0
     6,PMK2(6,6)                                                        0
C***                                                                    0
      DIMENSION B60(6,6),FKDT(6,6),SUME(6,6),SUME1(6,6)                 0
C***                                                                    0
    1 CONTINUE                                                          0
      PRINT 1002                                                        0
 1002 FORMAT(1H ,'TYPE &INP FILE= &END')                                0
      READ(5,INP)                                                       0
      INF1=FILE(1)                                                      0
      INF2=FILE(2)                                                      0
      PRINT 2000,FILE                                                   0
 2000 FORMAT(2I10)                                                      0
      PRINT 1004                                                        0
 1004 FORMAT(1H ,'TYPE &DAT DATA= &END')                                0
      READ(INF1,DAT)                                                    0
      IF(SOF)GOTO 92                                                    0
      PRINT 1003                                                        0
 1003 FORMAT(1H ,'IF EVERYTHING O.K. TYPE &OK GO=.TRUE.&END')           0
      GO=.TRUE.                                                         0
      READ(5,OK)                                                        0
      IF(GO)GOTO 10                                                     0
      GOTO 1                                                            0
   10 CONTINUE                                                          0
C***                                                                    0
C***                                                                    0
      KSTEP=NSTEP                                                       0
      KSTEP1=0                                                          0
C***                                                                    0
      KSTEPA=KSTEP                                                      0
C*                                                                      0
      PI=4.0D0*DATAN(1.0D0)                                             0
      CRAD=180.0D0/PI                                                   0
```

```
C***                                                                    OPT
      READ(10) (XAS(I,1),I=1,6)                                         OPT
      READ(12'KSTEPA) (XPK12(I),I=1,11)                                 OPT
     1,(XMK12(I),I=1,11),((PPK12(I,J),I=1,11),J=1,11)                   OPT
     2,((PMK12(I,J),I=1,11),J=1,11)                                     OPT
C*                                                                      OPT
      DO 431 I=1,NXP                                                    OPT
      XPK1(I)=XPK12(I)                                                  OPT
  431 XMK1(I)=XMK12(I)                                                  OPT
      DO 432 I=1,NXP                                                    OPT
      DO 432 J=1,NXP                                                    OPT
      PPK1(I,J)=PPK12(I,J)                                              OPT
  432 PMK1(I,J)=PMK12(I,J)                                              OPT
C***                                                                    OPT
      DO 581 I=1,NXP                                                    OPT
  581 XS(I)=XPK1(I)                                                     OPT
      DO 582 I=1,NXP                                                    OPT
      DO 582 J=1,NXP                                                    OPT
  582 PS(I,J)=PPK1(I,J)                                                 OPT
      KSTEPG=KSTEP                                                      OPT
      DO 709 I=1,NXP                                                    OPT
  709 XS1(I)=XS(I)                                                      OPT
      DO 710 I=1,NXP                                                    OPT
      DO 710 J=1,NXP                                                    OPT
  710 PS1(I,J)=PS(I,J)                                                  OPT
      XS1(7)=XPK12(7)                                                   OPT
      XS1(8)=XPK12(8)                                                   OPT
      XS1(9)=XPK12(9)                                                   OPT
      DO 801 I=7,9                                                      OPT
      DO 801 J=1,9                                                      OPT
  801 PS1(I,J)=PPK12(I,J)                                               OPT
      DO 802 I=1,6                                                      OPT
      DO 802 J=7,9                                                      OPT
  802 PS1(I,J)=PPK12(I,J)                                               OPT
C***                                                                    OPT
      XS1(10)=XPK12(10)                                                 OPT
      XS1(11)=XPK12(11)                                                 OPT
      WRITE(17'KSTEPG) (XS1(I),I=1,11)                                  OPT
     1,((PS1(I,J),I=1,9),J=1,9)                                         OPT
C***                                                                    OPT
      DO 591 I=1,NXP                                                    OPT
      DO 591 J=1,NXP                                                    OPT
  591 FK(I,J)=0.                                                        OPT
C***                                                                    OPT
C***                                                                    OPT
  301 CONTINUE                                                          OPT
      KSTEP=KSTEP-1                                                     OPT
      IF(KSTEP.LT.1)GOTO 311                                            OPT
      KSTEP1=KSTEP1+1                                                   OPT
C***                                                                    OPT
      KSTEPA=KSTEP                                                      OPT
C***                                                                    OPT
      READ(10) (XAS(I,1),I=1,6)                                         OPT
      READ(12'KSTEPA) (XPK12(I),I=1,11)                                 OPT
     1,(XMK12(I),I=1,11),((PPK12(I,J),I=1,11),J=1,11)                   OPT
```

```
     2,((PMK12(I,J),I=1,11),J=1,11)
C*
      DO 441 I=1,NXP
      XPK(I)=XPK12(I)
  441 XMK(I)=XMK12(I)
      DO 442 I=1,NXP
      DO 442 J=1,NXP
      PPK(I,J)=PPK12(I,J)
  442 PMK(I,J)=PMK12(I,J)
C***
C***FK-MATRIX COMPUTATION
      WP=XAS(1,1)
      WQ=XAS(2,1)
      WR=XAS(3,1)
      PHI=XAS(4,1)
      TET=XAS(5,1)
      PSI=XAS(6,1)
      SNT=DSIN(TET)
      CST=DCOS(TET)
      SNF=DSIN(PHI)
      CSF=DCOS(PHI)
      SNP=DSIN(PSI)
      CSP=DCOS(PSI)
C***
      CEB11=CST*CSP
      CEB12=CST*SNP
      CEB13=-SNT
      CEB21=SNF*SNT*CSP-CSF*SNP
      CEB22=SNF*SNT*SNP+CSF*CSP
      CEB23=+SNF*CST
      CEB31=SNT*CSF*CSP+SNF*SNP
      CEB32=CSF*SNT*SNP-SNF*CSP
      CEB33=+CST*CSF
C***
      XE=XPK(1)
      YE=XPK(2)
      ZE=XPK(3)
      USPEED=XPK(4)
      VSPEED=XPK(5)
      WSPEED=XPK(6)
C***
      WX=XPK12(7)
      WY=XPK12(8)
      WZ=XPK12(9)
C***
      TLAM=TLAM0+XE/AGLOBE
      COST=DCOS(TLAM)
      SINT=DSIN(TLAM)
      TANT=SINT/COST
      SIN2T=2*SINT*COST
      COS2T=COST*COST-SINT*SINT
      C1111=1.0D0-ZE/AGLOBE-.5D0*EPS2*COS2T
      C112=1/C1111
C*
C*
```

```
      C141=C112*(ZE/AGLOBE+.5*EPS2*COS2T)                                    OP
      C111=(CEB11*USPEED+CEB21*VSPEED+CEB31*WSPEED+WX)/AGLOBE                OP
      C211=(CEB12*USPEED+CEB22*VSPEED+CEB32*WSPEED+WY)/AGLOBE                OP
      C241=-C112*YE*TANT/AGLOBE                                              OP
      C341=C112*EPS2*SIN2T                                                   OP
      C56=OMEGA*(CEB11*COST-CEB13*SINT)                                      OP
      C64=OMEGA*(CEB21*COST-CEB23*SINT)                                      OP
      C45=OMEGA*(CEB31*COST-CEB33*SINT)                                      OP
C***                                                                         OP
      C413=OMEGA*(CEB11*SINT+CEB13*COST)                                     OP
      C412=OMEGA*(CEB21*SINT+CEB23*COST)                                     OP
      C411=OMEGA*(CEB31*SINT+CEB33*COST)                                     OP
      CENT1=-OMEGA**2*AGLOBE*C1111*.5*SIN2T                                  OP
      CENT2=-OMEGA**2*AGLOBE*C1111*COST**2                                   OP
      C47=2*(+WR*CEB21-WQ*CEB31)+OMEGA*CEB12*SINT                            OP
      C48=2*(+WR*CEB22-WQ*CEB32)-C413                                        OP
      C49=2*(+WR*CEB23-WQ*CEB33)-OMEGA*CEB12*COST                            OP
      C57=2*(-WR*CEB11+WP*CEB31)+OMEGA*CEB22*SINT                            OP
      C58=2*(-WR*CEB12+WP*CEB32)-C412                                        OP
      C59=2*(-WR*CEB13+WP*CEB33)-OMEGA*CEB22*COST                            OP
      C67=2*(+WQ*CEB11-WP*CEB21)+OMEGA*CEB32*SINT                            OP
      C68=2*(+WQ*CEB12-WP*CEB22)-C411                                        OP
      C69=2*(+WQ*CEB13-WP*CEB23)-OMEGA*CEB32*COST                            OP
C*                                                                           OP
      C1122=C112*C112                                                        OP
      C2112=C211*C1122                                                       OP
      C13=C111*C1122                                                         OP
      C11=-EPS2*SIN2T*C13                                                    OP
      C31=C111*C112*EPS2*(2*COS2T-C112*EPS2*SIN2T*SIN2T)                     OP
      C33=C13*EPS2*SIN2T                                                     OP
      C21=-EPS2*SIN2T*C2112+C13*(-C1111+.5D0*EPS2*SIN2T*SIN2T)*YE/           OP
     1 AGLOBE/COST/COST                                                      OP
      C22=-C111*C112*TANT                                                    OP
      C23=C2112-C13*TANT*YE/AGLOBE                                           OP
      C14=C141*CEB11                                                         OP
      C15=C141*CEB21                                                         OP
      C16=C141*CEB31                                                         OP
      C24=C241*CEB11+C141*CEB12                                              OP
      C25=C241*CEB21+C141*CEB22                                              OP
      C26=C241*CEB31+C141*CEB32                                              OP
      C34=C341*CEB11                                                         OP
      C35=C341*CEB21                                                         OP
      C36=C341*CEB31                                                         OP
      C17=C141                                                               OP
      C27=C241                                                               OP
      C28=C141                                                               OP
      C37=C341                                                               OP
      C411=OMEGA*(CEB31*SINT+CEB33*COST)                                     OP
      C412=OMEGA*(CEB21*SINT+CEB23*COST)                                     OP
      C413=OMEGA*(CEB11*SINT+CEB13*COST)                                     OP
      C433=OMEGA*COST                                                        OP
      C43=C433*C413                                                          OP
      C53=C433*C412                                                          OP
      C63=C433*C411                                                          OP
      COST1=COST*OMEGA/AGLOBE                                                OP
```

```
      SINT1=SINT*OMEGA/AGLOBE
      C4111=(C1111*COS2T+.5D0*EPS2*SIN2T*SIN2T)*OMEGA*OMEGA
      C4112=(C1111*SIN2T-     EPS2*SIN2T*COST*COST)*OMEGA*OMEGA
      C41=(WSPEED*C412-VSPEED*C411)/AGLOBE
     1-CEB11*C4111+CEB13*C4112+COST1*(WX*CEB12-WY*CEB11)+SINT1*(
     2 WY*CEB13+WZ*CEB12)
      C51=(USPEED*C411-WSPEED*C413)/AGLOBE
     1-CEB21*C4111+CEB23*C4112+COST1*(WX*CEB22-WY*CEB21)+SINT1*(
     2 WY*CEB23+WZ*CEB22)
      C61=(VSPEED*C413-USPEED*C412)/AGLOBE
     1-CEB31*C4111+CEB33*C4112+COST1*(WX*CEB32-WY*CEB31)+SINT1*(
     2 WY*CEB33+WZ*CEB32)
      C65=-C56
      C46=-C64
      C54=-C45
      FK(1,1)=C11
      FK(2,1)=C21
      FK(3,1)=C31
      FK(4,1)=C41
      FK(5,1)=C51
      FK(6,1)=C61
      FK(2,2)=C22
      FK(1,3)=C13
      FK(2,3)=C23
      FK(3,3)=C33
      FK(4,3)=C43
      FK(5,3)=C53
      FK(6,3)=C63
      FK(1,4)=CEB11+C14
      FK(2,4)=CEB12+C24
      FK(3,4)=+CEB13+C34
      FK(1,5)=CEB21+C15
      FK(2,5)=CEB22+C25
      FK(3,5)=+CEB23+C35
      FK(1,6)=CEB31+C16
      FK(2,6)=CEB32+C26
      FK(3,6)=+CEB33+C36
      FK(5,4)=-WR+C54
      FK(6,4)=WQ+C64
      FK(4,5)=WR+C45
      FK(6,5)=-WP+C65
      FK(4,6)=-WQ+C46
      FK(5,6)=WP+C56
C*
C*CALLING THE SUBROUTINE FOR COMPUTATION OF THE STATE TRANSITION MATRIX
C***
      CALL CSTM(FK,PERCNT,DT,TMAT,B60,FKDT,SUME,SUME1,NXP,NTERMS)
      DO 600 I=1,NXP
      DO 600 J=1,NXP
  600 TMATT(J,I)=TMAT(I,J)
C***
      DO 701 I=1,NXP
      DO 701 J=1,NXP
  701 PMK2(I,J)=PMK1(I,J)
C***
```

```
      CALL LINV1F(PMK2,NXP,NXP,PINV,IDGT,WKAREA,IER1)                    OP
      CALL VMULFF(PPK,TMATT,NXP,NXP,NXP,NXP,NXP,PTMATT,NXP,IER2)         OP
      CALL VMULFF(PTMATT,PINV,NXP,NXP,NXP,NXP,NXP,AK,NXP,IER3)           OP
      DO 601 I=1,NXP                                                     OP
      DO 601 J=1,NXP                                                     OP
  601 AKT(J,I)=AK(I,J)                                                   OP
      DO 602 I=1,NXP                                                     OP
  602 DELX(I,1)=XS(I)-XMK1(I)                                            OP
      DO 603 I=1,NXP                                                     OP
      DO 603 J=1,NXP                                                     OP
  603 DELP(I,J)=PS(I,J)-PMK1(I,J)                                        OP
      CALL VMULFF(AK,DELX,NXP,NXP,1,NXP,NXP,DELXES,NXP,IER4)             OP
      DO 604 I=1,NXP                                                     OP
  604 XS(I)=XPK(I)+DELXES(I,1)                                           OP
      CALL VMULFF(AK,DELP,NXP,NXP,NXP,NXP,NXP,AKDELP,NXP,IER5)           OP
      CALL VMULFF(AKDELP,AKT,NXP,NXP,NXP,NXP,NXP,ADPAT,NXP,IER6)         OP
      DO 605 I=1,NXP                                                     OP
      DO 605 J=1,NXP                                                     OP
  605 PS(I,J)=PPK(I,J)+ADPAT(I,J)                                        OP
C***                                                                     OP
      IF(KSTEP1.LT.5)GOTO 253                                            OP
      KSTEP1=0                                                           OP
      DO 251 I=1,NXP                                                     OP
      DO 252 J=1,NXP                                                     OP
      IF(I.LE.J)GOTO 252                                                 OP
      PS(I,J)=.5D0*(PS(I,J)+PS(J,I))                                     OP
      PS(J,I)=PS(I,J)                                                    OP
  252 CONTINUE                                                           OP
  251 CONTINUE                                                           OP
  253 CONTINUE                                                           OP
C***                                                                     OP
      DO 711 I=1,NXP                                                     OP
  711 XS1(I)=XS(I)                                                       OP
      DO 712 I=1,NXP                                                     OP
      DO 712 J=1,NXP                                                     OP
  712 PS1(I,J)=PS(I,J)                                                   OP
      KSTEPG=KSTEP                                                       OP
      XS1(7)=XPK12(7)                                                    OP
      XS1(8)=XPK12(8)                                                    OP
      XS1(9)=XPK12(9)                                                    OP
      DO 803 I=7,9                                                       OP
      DO 803 J=1,9                                                       OP
  803 PS1(I,J)=PPK12(I,J)                                                OP
      DO 804 I=1,6                                                       OP
      DO 804 J=7,9                                                       OP
  804 PS1(I,J)=PPK12(I,J)                                                OP
      XS1(10)=XPK12(10)                                                  OP
      XS1(11)=XPK12(11)                                                  OP
      WRITE(17'KSTEPG) (XS1(I),I=1,11)                                   OP
     1,((PS1(I,J),I=1,9),J=1,9)                                          OP
C***COPY K-AREAS INTO (K+1)-AREAS I.E. INTO 'PREVIOUS' AREA,             OP
C***--GOING FROM END TO BEGINNING OF FILE.                               OP
      DO 631 I=1,NXP                                                     OP
      DO 631 J=1,NXP                                                     OP
  631 PMK1(I,J)=PMK(I,J)                                                 OP
```

```
      DO 632 I=1,NXP
  632 XMK1(I)=XMK(I)
C***
      GOTO 301
C***
C***
  311 CONTINUE
C***
C***
      GOTO 1
   92 CONTINUE
      STOP
      END
      BLOCK DATA
      IMPLICIT REAL*8(A-H,O-$)
      COMMON/DAT0/PERCNT,DT,TLAM0,OMEGA,AGLOBE,EPS2,IDGT,NSTEP,NXP,SOF
      LOGICAL SOF
      DATA SOF/ .FALSE. /,NSTEP/60/,NXP/6/
     1,PERCNT/.000001D0/,DT/1.0D0/
     2,IDGT/3/
     3,TLAM0/.700D0/
     4,OMEGA/.0000728D0/,AGLOBE/20940000.0D0/,EPS2/.0067D0/
      END
```

```
C***THIS PROGRAM CREATES A NON-DIRECT-ACCESS-DATA-FILE FOR XAS OR       OP
C***XBS FOR OUTPUT OR FURTHER PROCESSING                                OP
C*                                                                      OP
      DIMENSION J(15),Z(11)                                             OP
     1    ,RDME(7),XDME(7),YDME(7),ZDME(7)                             OP
      COMMON/DAT0/SOF,J,NSTEP,N,NAMES,TLAM0,AGLOBE                      OP
     1   ,EPS2,SMEW0,ISTDME,XST(7),YST(7),ZST(7)                        OP
      INTEGER FILE(2)                                                   OP
      DIMENSION NAMES(38),NAMES1(38),XS(11),PS(9,9),SUM(14),STDZ(10)    OP
     1       ,BIAS(11),SUM1(14),TEMP(14)                                OP
      LOGICAL GO,SOF                                                    OP
      NAMELIST/INP/FILE                                                 OP
      NAMELIST/OK/GO                                                    OP
      NAMELIST/DAT/SOF,J,NSTEP,N,TLAM0,AGLOBE                           OP
     1    ,EPS2,SMEW0,ISTDME,XST,YST,ZST                                OP
C***                                                                    OP
      DEFINE FILE 10(60,368,L,KSTEP1)                                   OP
C***                                                                    OP
    1 CONTINUE                                                          OP
      PRINT 1002                                                        OP
 1002 FORMAT(1H ,'TYPE &INP FILE= &END')                                OP
      READ(5,INP)                                                       OP
      INF1=FILE(1)                                                      OP
      INF2=FILE(2)                                                      OP
      PRINT 2000,FILE                                                   OP
 2000 FORMAT(2I10)                                                      OP
      PRINT 1004                                                        OP
 1004 FORMAT(1H ,'TYPE &DAT DATA= &END')                                OP
      READ(INF1,DAT)                                                    OP
      IF(SOF)GOTO 92                                                    OP
      PRINT 1003                                                        OP
 1003 FORMAT(1H ,'IF EVERYTHING O.K. TYPE &OK GO=.TRUE.&END')           OP
      GO=.TRUE.                                                         OP
      READ(5,OK)                                                        OP
      IF(GO)GOTO 10                                                     OP
      GOTO 1                                                            OP
   10 CONTINUE                                                          OP
C***                                                                    OP
      DO 331 I=1,14                                                     OP
      SUM1(I)=0.                                                        OP
  331 SUM(I)=0.                                                         OP
C***                                                                    OP
      DO 991 J1=1,NSTEP                                                 OP
      KSTEP1=J1                                                         OP
      READ(10'KSTEP1) (XS(I),I=1,11)                                    OP
     1,((PS(I,J7),I=1,9),J7=1,9)                                        OP
C***                                                                    OP
      COST=COS(TLAM0+XS(1)/AGLOBE)                                      OP
      XS(2)=XS(2)/COST                                                  OP
C***                                                                    OP
      DO 302 I=1,9                                                      OP
      DO 302 J8=1,9                                                     OP
      IF(PS(I,J8).LT.0.)PS(I,J8)=100.                                   OP
  302 PS(I,J8)=SQRT(PS(I,J8))                                           OP
C***                                                                    OP
```

```
      WRITE(11)(XS(I),I=1,9)
C***
      READ(14)(Z(I3),I3=1,11)
      IF(NSTEP.GT.150)GOTO 923
      WRITE(12,903)J1,(XS(I),I=1,6),(PS(I,I),I=1,6)
  903 FORMAT(' 'I10,12F10.3)
      WRITE(12,905)J1,(XS(I),I=7,9),(PS(I,I),I=7,9)
  905 FORMAT(' ',I10,6F20.3)
  923 CONTINUE
C***NOT TO WASTE TDISK SPACE, WHILE ACTUALLY PROCESSING
C****
      USPD=XS(4)
      VSPD=XS(5)
      WSPD=XS(6)
      XE=XS(1)
      YE=XS(2)*COST
C***XS(2) HAS BEEN REDEFINED AT THE BEGINNING OF THIS PROGRAM.
      ZE=XS(3)
      VAIR=SQRT(USPD**2+VSPD**2+WSPD**2)
      ALPHA=57.3*ATAN2(WSPD,USPD)
      BETA=57.3*ATAN2(VSPD,USPD)
      HM=-ZE
C***
      IF(J1.EQ.1)PRINT 931,XS(1),XS(2)
  931 FORMAT(' ',2F10.0)
C***
      IF(NSTEP.GT.150)GOTO 921
C***
      TLAM=TLAM0+XE/AGLOBE
      COST=COS(TLAM)
      SINT=SIN(TLAM)
      SMEW=SMEW0+YE/AGLOBE/COST
      COSS=COS(SMEW)
      SINS=SIN(SMEW)
      C1111=1.-.5*EPS2*COS(2*TLAM)
      AC1111=AGLOBE*C1111
      DO 301 I=1,ISTDME
      XDME(I)=AC1111*COST*COSS-(-ZST(I)+AGLOBE*(1.-.5*EPS2*COS(2*XST(I))
     1))*COS(XST(I))*COS(YST(I))
      YDME(I)=AC1111*COST*SINS-(-ZST(I)+AGLOBE*(1.-.5*EPS2*COS(2*XST(I))
     1))*COS(XST(I))*SIN(YST(I))
      ZDME(I)=AC1111*SINT     -(-ZST(I)+AGLOBE*(1.-.5*EPS2*COS(2*XST(I))
     1))*SIN(XST(I))
      RDME(I)=SQRT(XDME(I)**2+YDME(I)**2+ZDME(I)**2)
C*
C*    RDME(I)=SQRT((XE-XST(I))**2+(YE-YST(I))**2+(ZE-ZST(I))**2)
C*
  301 CONTINUE
C***
      WRITE(15,912)J1,Z(4),VAIR,Z(5),ALPHA,Z(6),BETA,Z(7),HM
     1,Z(8),RDME(1),Z(9),RDME(2),XS(7),XS(8),(PS(I,I),I=1,6)
C*****PRINT 911,J1,Z(4),VAIR,Z(5),ALPHA,Z(6),BETA,Z(7),HM
C****1   ,Z(8),RDME(1),Z(9),RDME(2),XS(7),XS(8)
  911 FORMAT(I4,F4.0,F4.0,4F4.1,2F6.0,4F8.0,2F4.0)
  912 FORMAT(' ',I5,2F5.0,4F4.1,2F6.0,4F8.0,2F4.0,4X,3F6.0,4X,3F5.1)
```

```
C***                                                                    OP
      TEMP( 1)=Z( 4)-VAIR                                               OP
      TEMP( 2)=Z( 5)-ALPHA                                              OP
      TEMP( 3)=Z( 6)-BETA                                               OP
      TEMP( 4)=Z( 7)-HM                                                 OP
      TEMP( 9)=Z( 8)-RDME(1)                                            OP
      TEMP(10)=Z( 9)-RDME(2)                                            OP
      TEMP( 5)=XS(7)                                                    OP
      TEMP( 6)=XS(8)                                                    OP
      TEMP( 7)=XS(10)                                                   OP
      TEMP( 8)=XS(11)                                                   OP
      DO 951 I51=1,10                                                   OP
      SUM1(I51)=SUM1(I51)+TEMP(I51)                                     OP
  951 SUM (I51)=SUM (I51)+TEMP(I51)**2                                  OP
      GOTO 922                                                          OP
  921 CONTINUE                                                          OP
      WRITE(15,913)J1,Z(4),VAIR,Z(5),ALPHA,Z(6),BETA,Z(7),HM            OP
     1,Z(8),XS(1),Z(9),XS(2),XS(7),XS(8)                                OP
  913 FORMAT(' ',I5,2F5.0,4F4.1,2F6.0,4F8.0,2F4.0,4X,18X,4X,15X)        OP
C*****PRINT 911,J1,Z(4),VAIR,Z(5),ALPHA,Z(6),BETA,Z(7),HM              OP
C*****1   ,Z(8),XS(1),Z(9),XS(2),XS(7),XS(8)                          OP
  922 CONTINUE                                                          OP
C****                                                                   OP
C*****PRINT 996,J1,(XS(I),I=1,6)                                        OP
  996 FORMAT(' ',I7,6F10.3)                                             OP
C*****PRINT 997,J1,(XS(I),I=7,9)                                        OP
  997 FORMAT(' ',I7,3F20.3)                                             OP
  991 CONTINUE                                                          OP
C***                                                                    OP
      IF(NSTEP.GT.60)GOTO 953                                           OP
      DO 952 I=1,8                                                      OP
      BIAS(I)=SUM1(I)/60                                                OP
      TEMP2=SUM(I)/59-BIAS(I)**2                                        OP
      IF(TEMP2.LT.0.)TEMP2=100.                                         OP
  952 STDZ(I)=SQRT(TEMP2)                                               OP
      BIAS( 9)=SUM1( 9)/60                                              OP
      BIAS(10)=SUM1(10)/60                                              OP
      TEMP3=SUM( 9)/59-(BIAS( 9)+BIAS(7))**2                           OP
      TEMP4=SUM(10)/59-(BIAS(10)+BIAS(8))**2                           OP
      IF(TEMP3.LT.0.)TEMP3=100.                                         OP
      IF(TEMP4.LT.0.)TEMP4=100.                                         OP
      STDZ( 9)=SQRT(TEMP3)                                              OP
      STDZ(10)=SQRT(TEMP4)                                              OP
      WRITE(15,914)(PS(I,I),I=1,6),(STDZ(I1),I1=1,4),STDZ(9),STDZ(10)   OP
  914 FORMAT(' ',F10.0,2F10.1,3F10.0,4X,F10.0,2F10.1,3F10.0)            OP
      PRINT 915,(BIAS(I),I=1,4),BIAS(9),BIAS(10),(STDZ(I1),I1=1,4)      OP
     1         ,STDZ(9),STDZ(10)                                        OP
  915 FORMAT(' ',F6.0,2F6.1,3F6.0,7X,F6.0,2F6.1,3F6.0)                  OP
  953 CONTINUE                                                          OP
      ENDFILE 12                                                        OP
      ENDFILE 15                                                        OP
C***                                                                    OP
      PRINT 995,(PS(I,I),I=1,6)                                         OP
  995 FORMAT(' ',6F10.3)                                                OP
C*** IS THERE ANOTHER RUN TO BE GENERATED?                              OP
```

```
      GOTO 1                                                            C
   92 CONTINUE                                                          C
      STOP                                                              C
      END                                                               C
      BLOCK DATA                                                        C
      COMMON/DAT0/SOF,J,NSTEP,N,NAMES,TLAM0,AGLOBE                      C
     1    ,EPS2,SMEW0,ISTDME,XST(7),YST(7),ZST(7)                      C
      DIMENSION J(15),NAMES(38)                                         C
      LOGICAL SOF                                                       C
      DATA SOF/ .FALSE. /,J/38,2,23,5,26,6,27,14,24,15,25,29,18,2*0/,   C
     ANSTEP/60/,N/13/                                                   C
     B,TLAM0/.700/,AGLOBE/20940000./                                    C
     C,ISTDME/2/,XST/.703,.6985,5*.706/,YST/-1.297,-1.2985,5*-1.294/    C
     D,ZST/7*0./,EPS2/.0067/,SMEW0/-1.300/                              C
     1,NAMES/'DME1','CLDE',' Q  ',' NZ ','WHDA','PEDR','BETA',' P  '   C
     2,' R  ',' NY ',' NX ','ALFA','DME2','HADT','LEDF','TRDE','THET'  C
     3,' V  ','PSI ','PHI ','TRDR','TRDA','PODE','PODT','PODF','PODA'  C
     4,'PODR','VOR1','HBAR','ALS ','LMLS','GMLS','VOR2','INDF','HDIG'  C
     5,'LGHT','MDSW','TIME'/                                            C
      END                                                               C
```

APPENDIX C

COMPUTER SYSTEMS FOR PREPROCESSING AND POST-FLIGHT DATA REDUCTION

Post-flight data handling begins using the HP 1000 digital computer located at Princeton University's Gas Dynamics Laboratory. The raw data is transferred to a 9-track, 1600 BPI magnetic tape that can be processed on either the IBM 4341 or the IBM 3033 computer. The following block-diagram summarizes the described procedure:

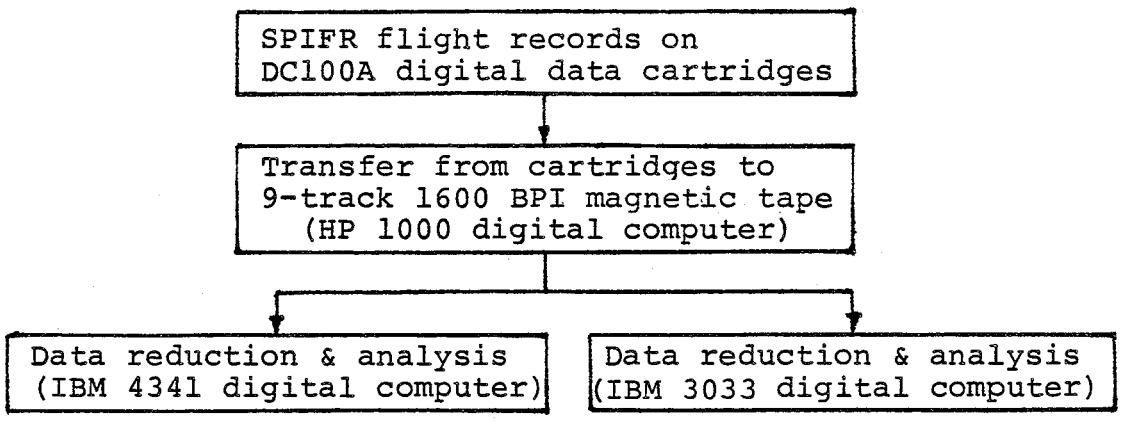

Figure C-1. Data Reduction Procedure.

The FORTRAN program CAT9 controls the transfer from the DC100A cartridges to the 9-track magnetic tape. The FORTRAN program RAWY1 converts 16-bit binary-formatted data into IBM-compatible decimal integer format and arranges the data in physical time vectors. The FORTRAN program SPIFY1 completes the preprocessing by converting the decimal integer time vectors into voltage and then into engineering units, also

converting Indicated Air Speed (IAS) to True Air Speed (TAS).

The SPIFR data storage policy is to preserve both the raw flight-test data and the preprocessed data on magnetic tapes (9-track, 1600 BPI), which makes it compatible for further analysis on both the IBM 4341 and the IBM 3033 machines. Thus, two copies of the raw integer data (RAWY1 output file) and one copy with engineering unit time-vectors (SPIFY1 output file)-for further processing (analysis, tabular printouts or plotting) are preserved.

TRANSFER FROM CARTRIDGES TO TAPE

```
&CAT9  T=00004 IS ON CR00005 USING 00012 BLKS R=0000

0001  FTN4,L
0002        PROGRAM CAT9(3,99), VERSION OF 4 JUNE 1981
0003  C
0004  C     PROGRAM TO COPY BINARY DATA FROM CASSETTE TO IBM COMPATIBLE
0005  C     TAPE DRIVE.
0006  C
0007  C     LOADING THE PROGRAM
0008  C        :RU,LOADR,*F4X,%CAT9
0009  C
0010  C     RUNNING THE PROGRAM
0011  C        :RU,CAT9,P1,P2
0012  C           WHERE P1 - IS THE LOGICAL UNIT NUMBER OF YOUR TERMINAL
0013  C                 P2 - IS THE LOGICAL UNIT NUMBER OF THE MAG TAPE
0014  C
0015  C
0016        INTEGER IBUFF(128),IMORE,ISTAT,ITLOG,PARMS(5),NBLCK
0017        EQUIVALENCE (PARMS(1),LUCRT),(PARMS(2),MTLU)
0018        CALL RMPAR(PARMS)
0019        NBLCK=0
0020  C***READ FROM LEFT CARTRIDGE LU 4
0021
0022     21 CONTINUE
0023        CALL EXEC(1,100B+4,IBUFF,128)
0024  C     GET STATUS
0025        CALL ABREG(ISTAT,ITLOG)
0026        WRITE(LUCRT,47)ITLOG
0027     47 FORMAT(I10)
0028  C     CHECK FOR END OF FILE
0029        IF(IAND(ISTAT,200B) .EQ. 200B) GO TO 22
0030  C     CHECK FOR END OF TAPE
0031        IF(IAND(ISTAT,40B) .EQ. 40B) GO TO 22
0032  C     CHECK FOR END OF DATA
0033        IF(IAND(ISTAT,2).EQ.2)GO TO 22
0034  C***WRITE TO TAPE
0035        CALL EXEC(2,100B+MTLU,IBUFF,128)
0036        NBLCK=NBLCK+1
0037        WRITE(LUCRT,31)NBLCK
0038     31 FORMAT(I7)
0039        GOTO 21
0040     22 CONTINUE
0041        IF(ITLOG.LT.128) GO TO 41
0042        CALL EXEC(2,100B+MTLU,IBUFF,128)
0043        NBLCK=NBLCK+1
0044        WRITE(LUCRT,31)NBLCK
0045     41   WRITE(LUCRT,23)
0046     23 FORMAT('PLUG IN NEXT CARTRIDGE AND TYPE 1 OR IF LAST-TYPE 0')
0047        READ(LUCRT,*)IMORE
0048        IF(IMORE.EQ.1)GOTO 21
0049  C     WRITE TWO CONSECUTIVE END OF FILE MARKS
0050        CALL EXEC(3,0100B+MTLU)
0051        CALL EXEC(3,0100B+MTLU)
0052        STOP
```

FILE: RAWY1 FORTRAN A1 PRINCETON UNIVERSITY TIME-SHARING SYSTEM

```
      COMMON/DAT0/SOF,NB                                                    RA
      LOGICAL GO,SCF                                                        RA
      NAMELIST/INP/FILE                                                     RA
      INTEGER*2 A3(1200),A2(1700,38)                                        RA
      INTEGER*2 DATA(128)                                                   RA
      LOGICAL*1 DALOG(256)                                                  RA
      LOGICAL*1 SWLOG(256)                                                  RA
      INTEGER*2 DATA1(128)                                                  RA
      INTEGER*2 DATA2(128)                                                  RA
      EQUIVALENCE (DATA(1),DALOG(1)),(SWLOG(1),DATA1(1))                    RA
      INTEGER FILE(2)                                                       RA
      NAMELIST/OK/GO                                                        RA
      NAMELIST/DAT/SCF,NB                                                   RA
C***                                                                        RA
    1 CONTINUE                                                              RA
      PRINT 1002                                                            RA
 1002 FORMAT(1H ,'TYPE &INP FILE= &END')                                    RA
      READ(5,INP)                                                           RA
      INF1=FILE(1)                                                          RA
      INF2=FILE(2)                                                          RA
      PRINT 2000,FILE                                                       RA
 2000 FORMAT(2I10)                                                          RA
      PRINT 1004                                                            RA
 1004 FORMAT(1H ,'TYPE &DAT DATA= &END')                                    RA
      READ(INF1,DAT)                                                        RA
      IF(SOF)GOTO 92                                                        RA
      PRINT 1003                                                            RA
 1003 FORMAT(1H ,'IF EVERYTHING O.K. TYPE &OK GO=.TRUE.&END')               RA
      GO=.TRUE.                                                             RA
      READ(5,OK)                                                            RA
      IF(GO)GOTO 10                                                         RA
      GOTO 1                                                                RA
   10 CONTINUE                                                              RA
C***                                                                        RA
      I1=0                                                                  RA
      I2=0                                                                  RA
C***                                                                        RA
      READ(15,17)DATA                                                       RA
      DO 28 I=1,255,2                                                       RA
      SWLOG(I)=DALOG(I+1)                                                   RA
      SWLOG(I+1)=DALOG(I)                                                   RA
   28 CONTINUE                                                              RA
      GOTO 32                                                               RA
C***                                                                        RA
   99 CONTINUE                                                              RA
      DO 30 I=1,128                                                         RA
   30 DATA2(I)=DATA1(I)                                                     RA
      READ(15,17,END=100)DATA                                               RA
   17 FORMAT (128A2)                                                        RA
      DO 29 I=1,255,2                                                       RA
      SWLOG(I)=DALOG(I+1)                                                   RA
      SWLOG(I+1)=DALOG(I)                                                   RA
   29 CONTINUE                                                              RA
C***                                                                        RA
      DO 31 I=1,128                                                         RA
```

```
      IF(DATA2(I).NE.DATA1(I))GOTO 32                                   RAW
   31 CONTINUE                                                          RAW
      GOTO 99                                                           RAW
   32 CONTINUE                                                          RAW
C***                                                                    RAW
      I1=I1+1                                                           RAW
      IF(I1.EQ.8)GOTO 417                                               RAW
      DO 421 M=1,128                                                    RAW
      M3=M+(I1-1)*128                                                   RAW
  421 A3(M3)=DATA1(M)                                                   RAW
      GOTO 99                                                           RAW
  417 DO 418 M=1,92                                                     RAW
      M3=M+(I1-1)*128                                                   RAW
  418 A3(M3)=DATA1(M)                                                   RAW
C***M3=1-(128*8-36);I1=0-8;I2=NO. OF 2048-BYTE BLOCKS,                  RAW
C***READ FROM TAPE INTO A3(EACH OVERWRITING THE PREVIOUS).              RAW
      I2=I2+1                                                           RAW
      K1=26*(I2-1)+1                                                    RAW
      K2=K1+25                                                          RAW
C*K HAS A SPAN OF 26 AS 1024=38*26+36                                   RAW
C***                                                                    RAW
      J7=0                                                              RAW
      DO 431 K=K1,K2                                                    RAW
      IF(K.GT.NB)GOTO 437                                               RAW
      DO 432 J=1,38                                                     RAW
  432 A2(K,J)=A3(J7+J)                                                  RAW
      J7=J7+38                                                          RAW
  431 CONTINUE                                                          RAW
      I1=0                                                              RAW
      GOTO 99                                                           RAW
  100 CONTINUE                                                          RAW
C***                                                                    RAW
      PRINT 441                                                         RAW
  441 FORMAT(1H ,'EOT;DECREASE NB AND RERUN AS A NEW JOB')              RAW
C***                                                                    RAW
  437 CONTINUE                                                          RAW
      KSOF=K-1                                                          RAW
   27 FORMAT(1H ,I10)                                                   RAW
      PRINT 27,KSOF                                                     RAW
      DO 531 J=1,38                                                     RAW
  531 WRITE(9)(A2(K0,J),K0=1,KSOF)                                      RAW
      ENDFILE 9                                                         RAW
C***                                                                    RAW
      GOTO 1                                                            RAW
   92 CONTINUE                                                          RAW
      STOP                                                              RAW
      END                                                               RAW
      BLOCK DATA                                                        RAW
      COMMON/DATO/SOF,NB                                                RAW
      LOGICAL SOF                                                       RAW
      DATA SOF/ .FALSE. /,NB/256/                                       RAW
      END                                                               RAW
```

```
FILE: SPIFY1   FORTRAN  A1  PRINCETON UNIVERSITY TIME-SHARING SYSTEM

      COMMON/DATC/SOF,VSLOPE,VCONST,PHSLOP,PHCONS,N11,DPNSTD                SP
      INTEGER FILE(2)                                                       SP
      DIMENSION A3(1700,38),PHSLOP(55),PHCONS(55)                           SP
      INTEGER*2 A2(1700,38)                                                 SP
      LOGICAL GO,SOF                                                        SP
      NAMELIST/INP/FILE                                                     SP
      NAMELIST/OK/GO                                                        SP
      NAMELIST/DAT/SOF,VSLOPE,VCONST,PHSLOP,PHCONS,N11,DPNSTD               SP
    1 CONTINUE                                                              SP
      PRINT 1002                                                            SP
 1002 FORMAT(1H ,'TYPE &INP FILE= &END')                                    SP
      READ(5,INP)                                                           SP
      INF1=FILE(1)                                                          SP
      INF2=FILE(2)                                                          SP
      PRINT 2000,FILE                                                       SP
 2000 FORMAT(2I10)                                                          SP
      PRINT 1004                                                            SP
 1004 FORMAT(1H ,'TYPE &DAT DATA= &END')                                    SP
      READ(INF1,DAT)                                                        SP
      IF(SOF)GOTO 92                                                        SP
      PRINT 1003                                                            SP
 1003 FORMAT(1H ,'IF EVERYTHING O.K. TYPE &OK GO=.TRUE.&END')               SP
      GO=.TRUE.                                                             SP
      READ(5,OK)                                                            SP
      IF(GO)GOTO 10                                                         SP
      GOTO 1                                                                SP
   10 CONTINUE                                                              SP
C***                                                                        SP
      DO 501 J=1,38                                                         SP
  501 READ(9)(A2(I,J),I=1,N11)                                              SP
C***NOW-INTO REAL PHYSICAL DATA.                                            SP
      DO 512 I=1,N11                                                        SP
      ISIGN=0                                                               SP
      IF(A2(I,1).LT.0)ISIGN=1                                               SP
C***65535=2**16-1,BECAUSE IF LEFTMOST OF THE 16-ZEROS-AND-ONES-FIELD        SP
C***IS ONE,IT ITSELF IS INTERPRETTED AS MINUS AND EACH OF THE OTHER         SP
C***15 BITS IS CHANGED(ONES TO ZEROS AND ZEROS TO ONES).                    SP
C***THUS,E.G.,A 16-ONES-FIELD IS INTERPRETTED AS -0 INSTEAD OF 2**16-1      SP
C***AND A ONE FOLLOWED BY 15 ZEROS IS -(2**15-1) INSTEAD OF 2**15           SP
  512 A3(I,1)=A2(I,1)+ISIGN*65535                                           SP
      DO 502 I=1,N11                                                        SP
      DO 503 J=2,12                                                         SP
      ISIGN=0                                                               SP
      IF(A2(I,J).LT.0)ISIGN=1                                               SP
  503 A3(I,J)=((A2(I,J)+ISIGN*65535)*VSLOPE/16.+VCONST)*PHSLOP(J)+          SP
     1PHCONS(J))                                                            SP
  502 CONTINUE                                                              SP
C***                                                                        SP
      DO 521 I=1,N11                                                        SP
      ISIGN=0                                                               SP
      IF(A2(I,13).LT.0)ISIGN=1                                              SP
  521 A3(I,13)=A2(I,13)+ISIGN*65535                                         SP
      DO 522 I=1,N11                                                        SP
      DO 523 J=14,34                                                        SP
      ISIGN=0                                                               SP
```

```
      IF(A2(I,J).LT.0)ISIGN=1                                          SPI
  523 A3(I,J)=(((A2(I,J)+ISIGN*65535)*VSLOPE/16.+VCONST)*PHSLOP(J)+    SPI
     1PHCONS(J))                                                       SPI
  522 CONTINUE                                                         SPI
C***                                                                   SPI
      DO 514 I=1,N11                                                   SPI
      DO 515 J=35,38                                                   SPI
      ISIGN=0                                                          SPI
      IF(A2(I,J).LT.0)ISIGN=1                                          SPI
  515 A3(I,J)=A2(I,J)+ISIGN*65535                                      SPI
  514 CONTINUE                                                         SPI
C***                                                                   SPI
      DO 591 I=1,N11                                                   SPI
  591 IF(A3(I,19).LT.0.)A3(I,19)=A3(I,19)+360.                         SPI
C***                                                                   SPI
      DO 601 I=2,N11,2                                                 SPI
  601 A3(I,1)=A3(I,13)                                                 SPI
      DO 602 I=3,N11,2                                                 SPI
  602 A3(I,1)=.5*(A3(I-1,1)+A3(I+1,1))                                 SPI
      A3(1,1)=A3(2,1)                                                  SPI
      N111=N11-2                                                       SPI
      DO 603 I=2,N111,2                                                SPI
  603 A3(I,13)=.5*(A3(I-1,13)+A3(I+1,13))                              SPI
      A3(N11,13)=A3(N11-1,13)                                          SPI
C***                                                                   SPI
C***PRAT=PRATIO;RRAT=RRATIO                                            SPI
      DO 611 I=1,N11                                                   SPI
      PRAT=(A3(I,29)+DPNSTD)/1013.3                                    SPI
      RRAT=PRAT**.81                                                   SPI
      A3(I,18)=1.689*A3(I,18)/SQRT(RRAT)                               SPI
      HCONST=EXP(ALOG(PRAT)/5.256)                                     SPI
      A3(I,29)=(1-HCONST)/.00000689                                    SPI
  611 CONTINUE                                                         SPI
C***                                                                   SPI
C***NOT TO LOSE ACCURACY,THE TIME VECTORS ARE STORED UNFORMATTED,I.E.  SPI
C***USING UNFORMATTED READ(AND WRITE WHEN RETRIEVING FOR FURTHER       SPI
C***PROCESSING).                                                       SPI
      DO 121 J=1,38                                                    SPI
  121 WRITE(10)(A3(I,J),I=1,N11)                                       SPI
      ENDFILE 10                                                       SPI
C***IS THERE ANOTHER RUN TO BE GENERATED?                              SPI
      GOTO 1                                                           SPI
   92 CONTINUE                                                         SPI
      STOP                                                             SPI
      END                                                              SPI
      BLOCK DATA                                                       SPI
      COMMON/DATO/SOF,VSLOPE,VCONST,PHSLOP,PHCONS,N11,DPNSTD           SPI
      DIMENSION PHSLOP(55),PHCONS(55)                                  SPI
      LOGICAL SOF                                                      SPI
      DATA SOF/ .FALSE. /,VSLOPE/.004884/,VCONST/-10./,                SPI
     1PHSLOP/1.,1.6583,-2.7604,-.20555,-8.2085,.2557,                  SPI
     2-3.0754,4.0811,-3.4664,-.05184,.05519,2.8611,                    SPI
     31.,.0508,.1020,-5.,3.1338,5.0623,                                SPI
     418.2787,-8.1864,5.,-5.,2.4703,.0513,                             SPI
     55.1310,-1.9589,2.4074,1.,15.275,2.8611,                          SPI
```

```
     6.25,.10,1.,.1,1.,3*1.,                                                SE
     717*1./,                                                               SE
     8PHCONS/0.,-3.2009,.458,-.02467,-.5304,.1055,                          SE
     9-.1019,-.0427,-.2048,-.0019,-.01233,13.7125,                          SE
     A0.,.492,-.0017,0.,.3805,99.9689,                                      SE
     B.0984,-.4821,0.,0.,-4.0193,.513,                                      SE
     C-23.8869,1.5698,3.5703,0.,950.,13.7125,                               SE
     D0.,0.,0.,0.,0.,0.,0.,0.,                                              SE
     E17*0./,                                                               SE
     FN11/10/                                                               SE
     G,DPNSTI/0./                                                           SE
      END                                                                   SE
```

APPENDIX D

INTEGRATION OF DISTANCE MEASURING EQUIPMENT (DME) INTO THE DATA COLLECTION SYSTEM

The DME component of the navigation/communication system has been integrated into the onboard experimental setup with the capability to sequence automatically available navigation stations and process the distance information using microprocessor control. The navigation/communication (NAV/COM) and the DME are part of the Bendix "BX-2000" product line of aircraft avionics. A digital information format is used in the Bendix NAV/COM and DME for frequency tuning. The DME receiver output to the pilot's indicator is a pulse-width signal which is compatible with digital processing techniques.

This appendix is sub-divided into sections relating to the external (microprocessor) tuning, distance signal decoding, and an overview of the DME system and specifications. The first two sections are specific to the Bendix system.

D-1. EXTERNAL DME TUNING

The Bendix DM-2031A DME receiver/transmitter has provisions for both "2 out of 5" tuning which is compatible with other manufacturers systems and a serial binary-coded-decimal (BCD) tuning. The serial tuning method is used by the Bendix NAV/COM and is implemented in the microprocessor tuning for compatibility. When the Bendix DME is installed with the Bendix NAV/COM, the DME serial tuning signal is the same one which is used for tuning the NAV receivers. As shown in Figure D-1, a switch located on the NAV/COM (Bendix CN-2011A) permits the pilot to select DME tuning paired with either NAV 1 or NAV 2. In the center-off or hold (H) position, no tuning signal is sent to the DME. Under this condition the DME continues to hold the last tuning selection and station frequency. The tuning signal contains a BCD format of the paired NAV frequency. (The NAV frequency is not the actual frequency used in the DME system, as will be explained in the overview section.)

The tuning signal is in the form of a twenty-bit asynchronous pulse-width modulated serial word. The serial data word format is shown in Figure D-2. The basic period of each word is 4.0 msec, and when supplied by the NAV/COM; the word rate is 250 Hz. However, a single word is sufficient to tune the DME. Note that the same format is used for the COM, NAV, DME and GS (glide slope) units in the Bendix product line. The first bit in the word is the synchronizing pulse. Each bit after the first is dedicated to a specific piece of information. The value of bits 2 through 7 is ignored in the current DME, but future units may use these bits as a device code.

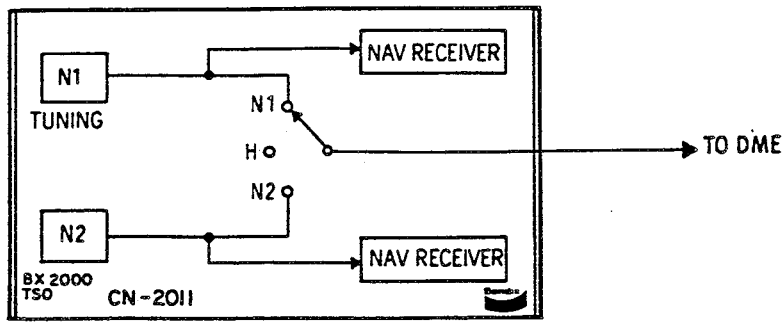

Figure D-1. DME Tuning Via NAV/COM.

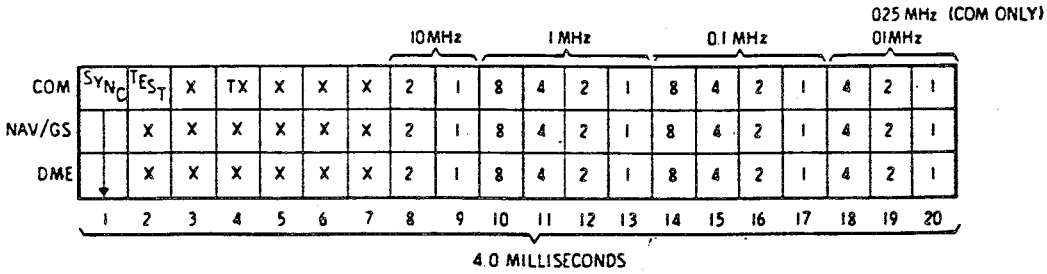

Figure D-2. Serial Data Word Format.

The bit format is shown in Figure D-3. Syncronization, logic "1", and logic "0" bits correspond to 150-, 100- and 50-microsecond duration pulses respectively. The decoder inside the DME (as well as NAV, COM and GS) is relatively tolerant of the actual pulse width (and word length) of the incoming signal. As mentioned previously, the synchronizing pulse (bit 1) indicates the beginning of the serial data word. During the synchronizing pulse, the signal level stays at logic 1 for 150 microseconds (nominal). The Bendix circuitry samples each bit at 125 microseconds to determine if that bit is the synchronizing pulse. A similar sample is made at 75 microseconds to differentiate logic 1 and logic 0 pulses. Hence, the minor variation in the pulse widths of the tuning signal will not compromise the proper functioning of the system.

A microprocessor software program which generates the bit pulses and data word format to tune the DME was written using simple software timing loops. This program was verified using an oscilliscope to check the pulse widths and data word format. Software programming of the station sequencing was not completed in time for implementation on the test program. The alternative tuning method to be described latter is an interim solution.

Electrical (hardware) interfacing for microprocessor tuning output to the DME input is shown in Figure D-4. A signal inversion is employed at the NAV/COM's DME tuning signal output (this was not shown in Figure D-1 for clarity) and the signal is again inverted at the DME. Thus, the signals on the interconnecting wires are inverted with respect to Figure D-3. The high level (pull-up) voltage

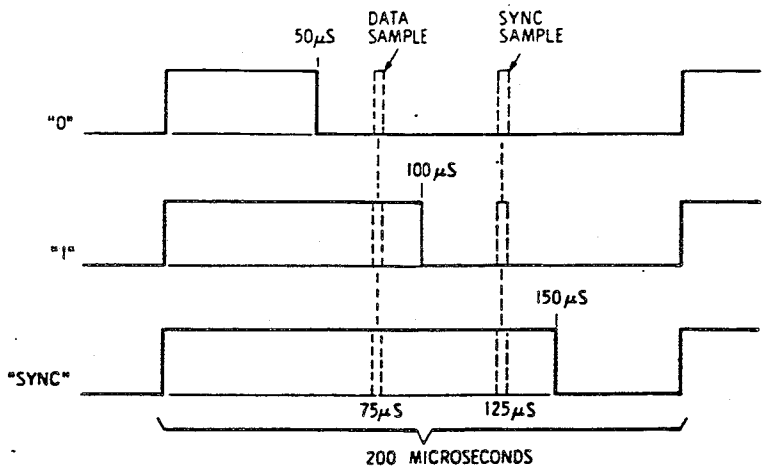

Figure D-3. Bit Format.

is 12 to 15 volts. An open collector buffer, preferrably with a 12 volt pull-up, may be used at the microprocessor side of the interface.

The alternative tuning method used in the current testing also is shown in Figure D-4. A switch located on the avionics section of the instrument panel allows the pilot to select normal NAV/COM (N) tuning or remote microprocessor (EXT) tuning. In the EXT position either the NAV 1 or NAV 2 tuning signal is routed to the DME, depending on the position of the relay shown. The relay is driven by a discrete digital output of the microprocessor. No changes in software logic were required for this implementation since the relay was driven in parallel with the "computer functioning" light on the instrument panel. The present rate of 0.5 Hz allows sufficient time for DME station lock-on and measurement of distance.

The selection switch N/EXT provides an additional function. In the EXT position, the displayed DME distance available on the one pilot's electronic course deviation instrument (ECDI) is blanked. The primary center panel DME indicator is not blanked, and the microprocessor station tuning of the DME can be verified by the safety pilot. The primary DME indicator can be switched by the safety pilot to display elapsed time or other function during flight tests.

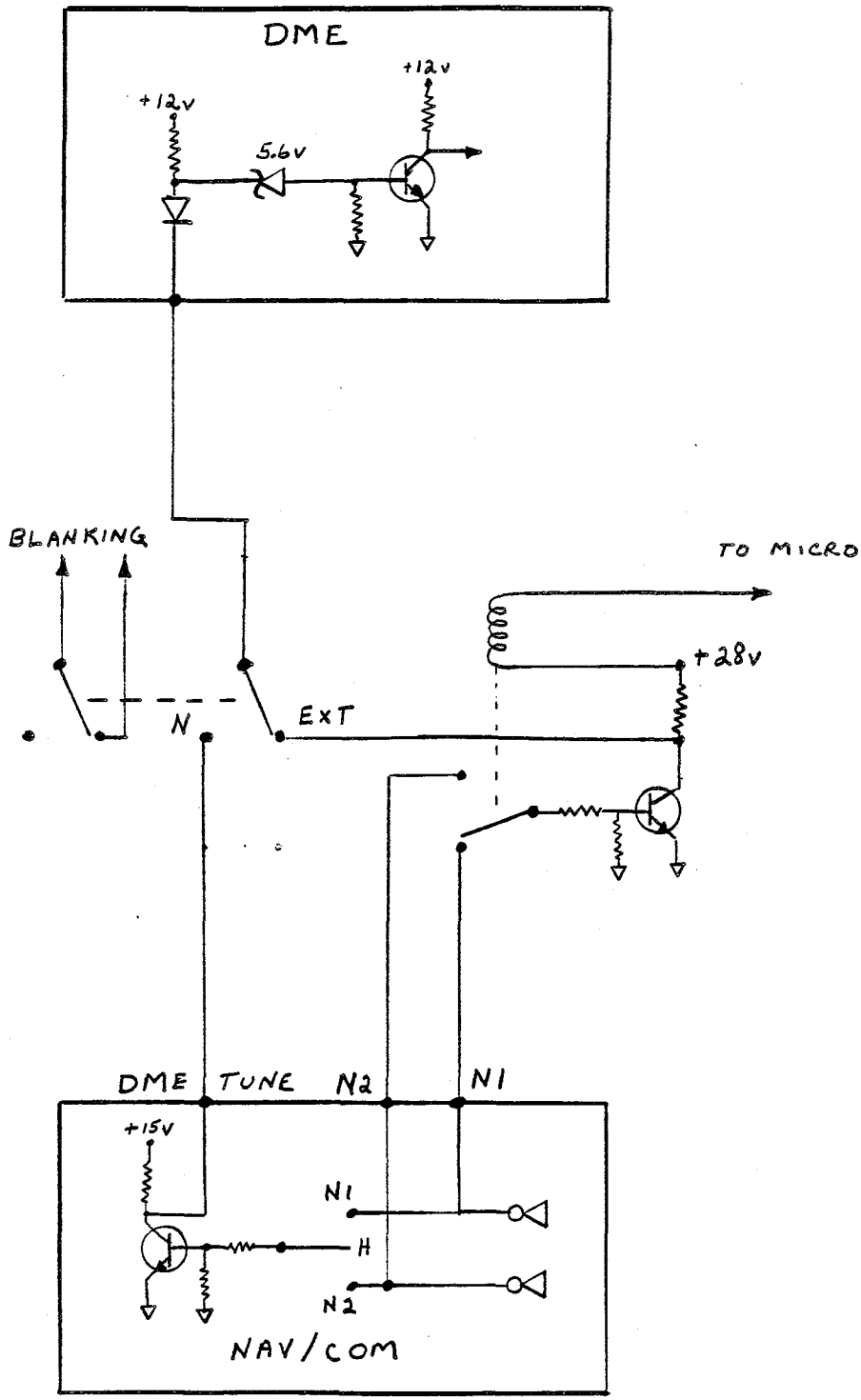

Figure D-4. DME Tuning Electrical Interface.

D-2. DME DISTANCE SIGNAL DECODING

Three signal outputs are generated by the Bendix DM-2031A DME receiver/transmitter: a pulse pair (RP1 and RP2) and a status signal (SEARCH). The time interval between RP1 and RP2 represents the slant range distance to the DME ground station. The digital logic interface, shown in Figure D-5, processes these three signals upon a DATA READ signal from the microprocessor. The distance represented the difference (RP2 - RP1) is presented to the microprocessor as a 16-bit (2-byte) word. The high-order bit of this data word is used to indicate the DME status (SEARCH).

The difference (RP2 - RP1) is measured by a 16-bit digital counter using a crystal controlled oscillator which operates at a frequency of 18 MHZ. Using the principle that RF energy travels one nautical mile and returns in 12.359 microseconds, the slant range from the aircraft to the ground station can be determined. Since the high-order bit is used for the status SEARCH signal, the maximum distance reading (15 bits) is 147 nautical miles. Although the interface clock frequency of 18 MHZ would suggest a measurement (counter) bit resolution of 27 feet, the actual resolution is determined by the processing within the Bendix DM-2031A. The LSI (large-scale-integration) chip that generates these pulses uses a 1.6 MHz clock (actually 1.61825 MHZ) which limits the (RP2 - RP1) difference increments to the equivalent of 0.05 nautical miles. Some other factors influencing measurement accuracy are discussed in the overview section.

The digital logic interface is presented in a simplified block diagram form in Figure D-6 for discussion of interface

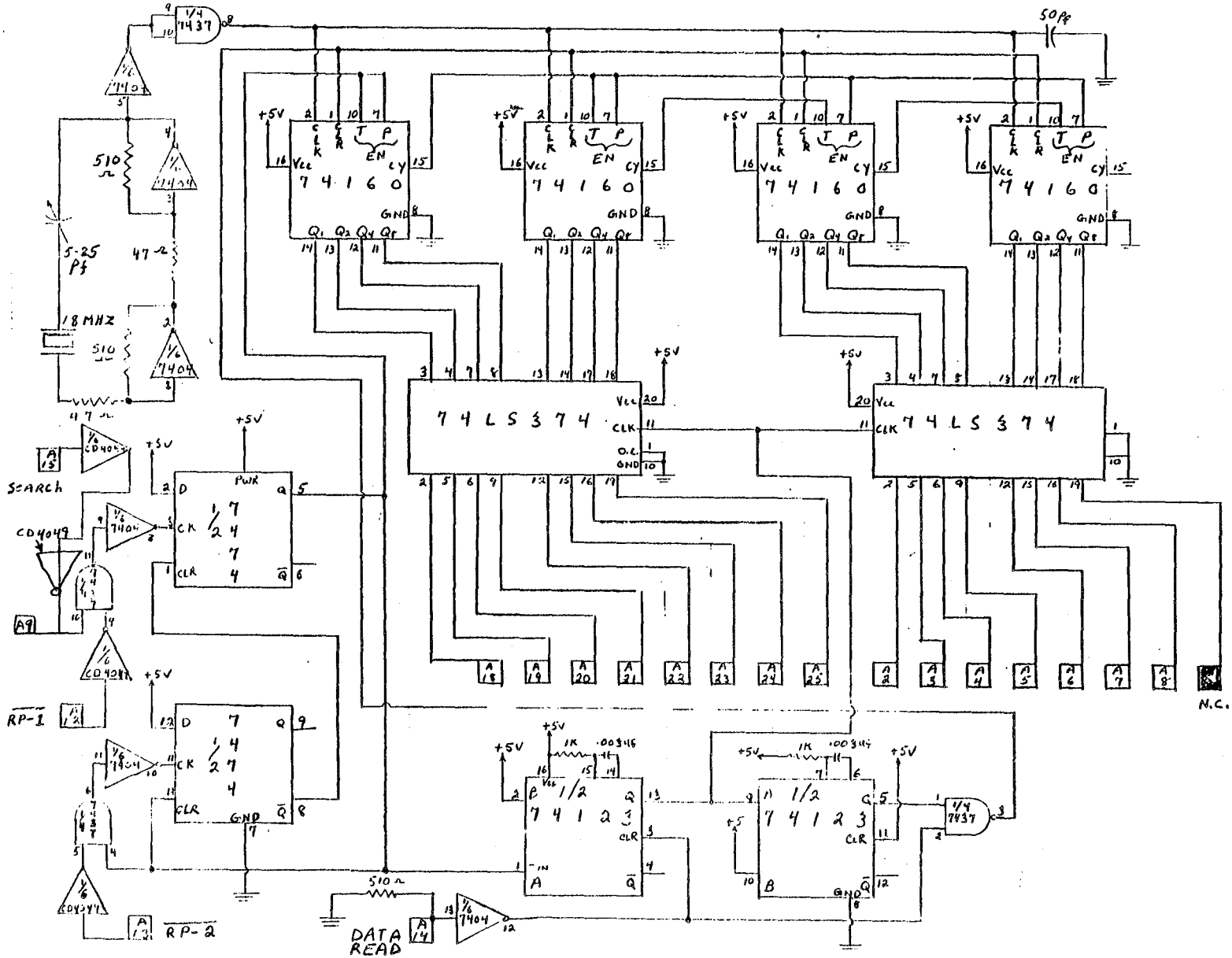

Figure D-5. DME - Microprocessor Electrical Interface.

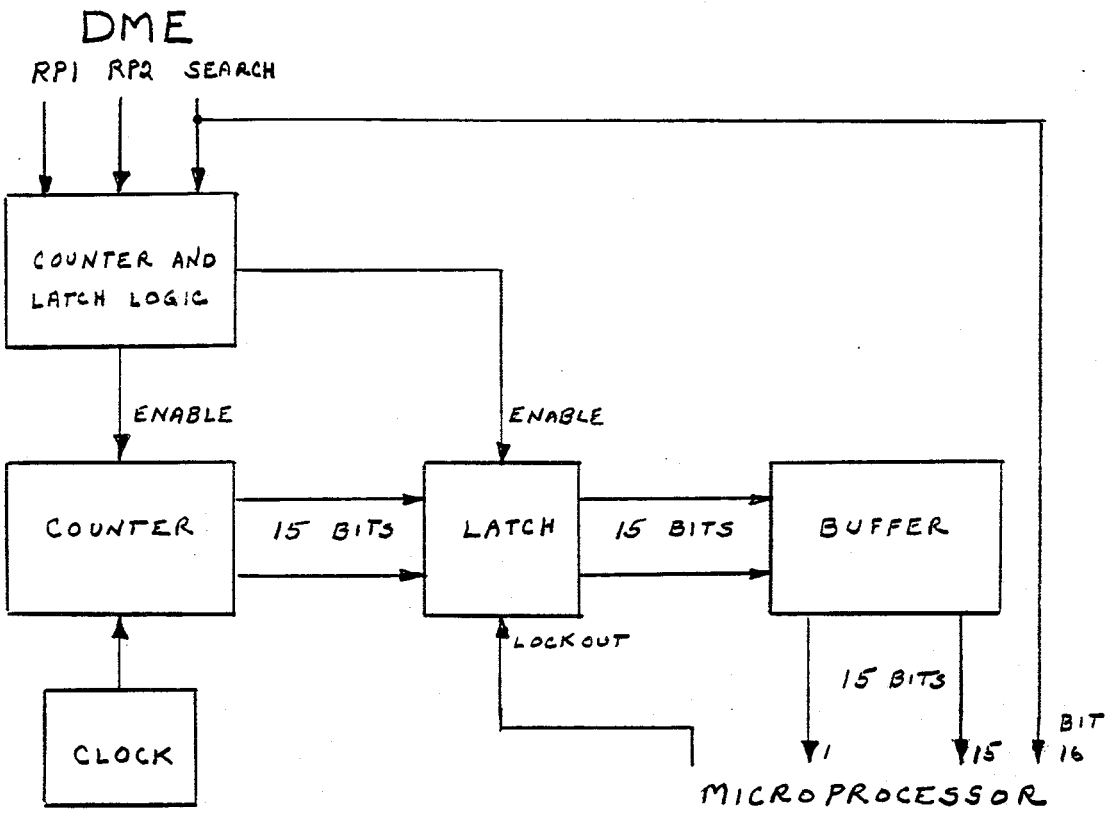

Figure D-6. DME Interface Block Diagram.

operation. The status of SEARCH is used to enable the counter as a precaution, although the absence of pulses RP1 and RP2 would preclude counter operation. The counter is started from a previously cleared (zero) value by the RP1 pulse from the DME. As noted previously, the counter rate is determined by the 18 MHZ referecne clock. The count is stopped by the RP2 pulse.

Two other events occur after receipt of RP2. After a very short delay, the count is transferred to the buffer via the latch control; when this operation is completed, the counter is reset or cleared. This chain of events continues to cycle as long as the signal DATA READ is not asserted by the microprocessor data collection system. Counter and buffer updates will take place at a 21 Hz rate during normal DME operation. When the microprocessor generates a DATA READ request, transfer of counter information to the buffer is inhibited. This signal is maintained by the microprocessor until the buffer has been read. This mode of operation guarantees that some data will be available so that the microprocessor will not "hang" in a wait state. The data in the buffer will normally be valid distance information measured within the last .05 sec of receipt of DATA READ. The signals RP1 and RP2 are not the raw pulses used by the DME interrogating a ground station; rather, they are generated by a sophisticated LSI chip. Corrections for delays in turnaround at the ground station and within the Bendix unit are applied so that the (RP2 - RP1) difference has no bias for true zero distance. Upon loss of the DME station, the (RP2 - RP1) pulses will continue to be sent by the LSI chip for up to 10 sec. A correction also is made to maintain the same rate of change (groundspeed) as observed

prior to station signal loss. The correction is 80% of the preobserved groundspeed to prevent a "backing up" indication on the pilot's indicator when the signal is reacquired. The consequences of the above and other effects are discussed in the following overview section.

D-3. DME/DATA COLLECTION OVERVIEW

The purpose of the DME system is to provide the pilot with slant range distance information from the aircraft to a selected DME ground facility. The system transmits interrogation signals in the form of pulse pairs to the selected ground station. The DME ground facility receives the interrogation signal and returns a reply signal (again a pulse pair) for each interrogation received. Multiple aircraft may interrogate the DME ground station.

The DME system operates in the frequency range of 978 MHZ to 1212 MHz. There are 200 DME channels which are paired with VHF NAV frequencies between 108.00 MHz and 117.95 MHz (100 "X" channels and 100 "Y" channels). For example DME channel 85X is paired with NAV frequency 113.80 MHz. The aircraft transmits the interrogation pulses at 1109 MHZ and receives the reply offset by 63 MHz at 1172 MHz. (Some X channels are offset below the transmission frequency.) On the .05 spacing VHF frequencies such as 113.85 MHz (paired DME channel 85Y) the same transmission frequency is used but the reply is offset opposite to that used for the X channel (1046 MHz). Since some electrical processing delay will take place from receipt of interrogation signal to reply signal, all replys are adjusted to a specific delay to permit accurate measurement of the elapsed time by the airborne distance measuring circuits. This delay is 50 μsec for "X" stations and 56 μsec for Y stations (measured between the <u>first</u> pulse of interrogation to the <u>first</u> pulse of reply).

The interrogation pulse pairs are spaced at 12 μsec for X channels and 36 μsec for Y channels. The reply pulse

pairs are 12 μsec and 30 μsec for X and Y respectively.

The DME ground facility continuously transmits a nominal 2700 pulse pairs per second squitter signal with a 1350 Hz identification morse code signal at 30-second intervals. The 1350 Hz identification signal consists of groups of evenly spaced pulse pairs. The ground station provides a reply pulse pair that replaces a squitter pulse pair 50 μsec after receiving an interrogation. The identification signal is available to the pilot as an audio tone to verify tuning and station selection.

When the DME is first tuned to a ground station, it must determine which reply pulses are to its interrogation pulses as opposed to those meant for other aircraft. Old model DME equipment frequently took 20 seconds or longer to achieve a lock-on and track. The Bendix DM-2031A specification for lock-on is less than 1 second. During the search period the interrogation rate is increased to 140 pulse pairs/sec to improve the detection time. This is reduced to 21 interrogations per sec during track. All DME units also use a variable pulse repetition rate to prevent synchronization of distance replies between other DME aircraft interrogators. A random jitter of the interrogation rate about the nominal of ± 1% is used in the Bendix DM-2031A.

The specification measurement accuracy of the Bendix DM-2031A is ± 0.1 nautical mile or .15 percent, whichever is larger. The minimum indication on the pilot's display of the Bendix DME system is 0.1 nautical mile. The output resolution of the signal to the indicator (RP1 - RP2) pulses is 0.05 nautical mile.

A possible source of error, both at the ground station and in the aircraft processing circuits, is proper pulse delay processing. The DME ground station error specification is ± 0.1 nautical miles indicating that the pulse delay (50 μsec on channel X) is within 1.2 μsec. This type of error, at a given ground station, and airborne unit should be predictable and could be removed from the data. Determination of this error is predicated on range measurement of multiple DME stations by the aircraft. A small dynamic error occurs with the data collection system since the measurement time may be in error by the update period (approximately 0.05 sec). In the implementation discussed here, an error due to signal loss is possible. Time difference information can continue up to 10 seconds after signal loss as mentioned previously. With the present scheme of sequencing stations every 2 seconds, the memory circuit is only partially charged, and it is unlikely that a memory generated signal will be obtained.

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15. Supplementary Notes

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16. Abstract

Research is being conducted to develop flying qualities criteria for Single Pilot Instrument Flight Rule (SPIFR) operations. Significant progress has been made with regard to most of the key issues encompassed in the SPIFR research program. The ARA aircraft has been modified and adapted for SPIFR operations. Aircraft configurations to be flight-tested have been chosen and matched on the ARA in-flight simulator, implementing modern control theory algorithms. Mission planning and experimental matrix design have been completed. Microprocessor software for the onboard data acquisition system has been debugged and flight-tested. Flight-path reconstruction procedure and the associated FORTRAN program are at a final stage of development. Work has begun on algorithms associated with the statistical analysis of flight test results and the SPIFR flying qualities criteria deduction.

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